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A Survey on Classification of Diabetic Foot Ulcer Using Machine Learning Algorithms

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Abstract

Diabetes is the most common metabolic disease among the people. This disease may cause problems in blood vessels, nerves and also in the eyes. These problems can cause the foot ulcer of Neuropathic ulcer and Ischemic ulcer. The main reason for this ulcer is the improper circulation of blood and damages in nerves. Because of these ulcers, many people have lost their legs and sometimes it even leads to death. All over the world, millions of people have been affected by this disease. In every thirty seconds, one person's leg is being amputated. So, the proper classification and early detection of foot ulcer is very important for a better treatment. This paper is mainly focused on the classification of foot ulcer with its detailed survey on various classification techniques such as Decision Tree, Random Forest, M5 tree model, Random Tree, REP Tree, Neural Networks, ZeroR, Naïve Bayes, Back Propagation Neural Network and Linear Regression model. These algorithms are evaluated using the kaggle dataset. Finally, it shows the comparison of the various classification algorithms.

Keywords: Diabetic foot ulcer, Machine Learning, Classification, Detection.

Introduction

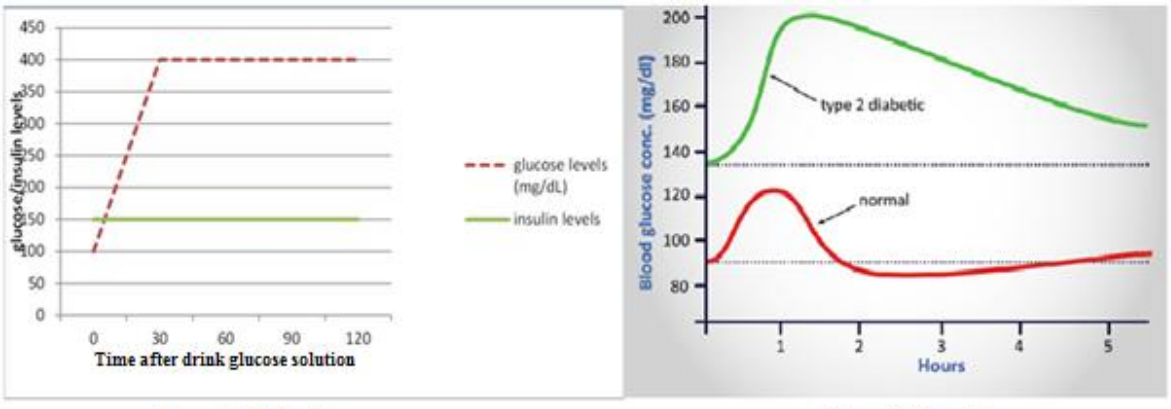
In today's world, most of the people have been affected by diabetes. The main reason for the diabetes is caused by the increase in blood glucose or blood sugar. As per the World Health Organization (WHO) report, the rate of the type 2 diabetic has increased all over the world across all income levels of the people. Nearly, 422 million people worldwide have diabetes and 1.6 million people are losing their lives due to the effects of diabetes every year. Diabetic cases are steadily increasing over the past few decades.

Carbohydrates consumed in our food are converted into sugar or glucose. Our pancreas produces a hormone named insulin to remove the glucose from the body. Sometimes the problem occurs when the insulin is not generated or insufficiently produced

by pancreas. This problem will increase the glucose or sugar levels in our body which is medically termed as “diabetes”.

Diabetes is also termed as diabetic mellitus. The various types of diabetics are: Type 1 diabetic, Type 2 diabetic and Gestational diabetics. Type 1 diabetic is an insulin dependent diabetic which occurs when our body attacks the pancreas with antibodies. Here, the pancreas is not producing any insulin in our body. Type 1 diabetic is the most dangerous diabetic and it causes more problems to the human. This diabetic will cause problems in the blood vessels, nerves and kidneys. Type 1 diabetic patient has a higher risk of heart attack. Type2 diabetic is non-insulin dependent diabetic. Here, the pancreas generates insufficient insulin or has a condition where the produced insulin is not used by the body. Today 90% of the people are affected by this Type 2 diabetic. For the past two decades most of the children and teens are also affected by this disease. It is milder than Type 1 diabetic and it can also cause some problems in the tiny blood vessels, nerves, eyes and kidneys. It is also the reason to raise heart attack. The problem in the tiny blood vessel is known as diabetic retinopathy, while the problem in the nerves is defined as diabetic neuropathy, and the problem in the kidney is called as diabetic nephropathy. Some of the women have insulin resistance and this condition is called gestational diabetic. In reference to the report, 2% to 10% of the pregnant women suffer from this diabetes [1].

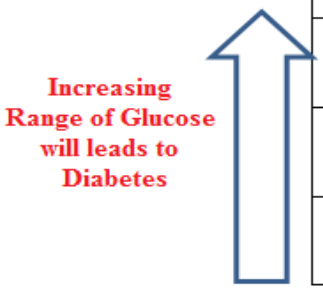
A1C test is used to find the levels of blood sugar in the body. A treatment for Type 1 diabetic involves injecting insulin into the fatty tissue of the body with the help of needles. Type 2 diabetes treatment does not involve any insulin. But it needs to be treated by proper exercises, eating the right food and maintaining a healthy weight. Besides these diabetic, 1% to 5% of the people suffer from other forms of diseases in pancreas and others caused by surgeries and infections. Figure 1 shows the graphical representation of type 1 and type 2 diabetes [1].



Type 1 Diabetic Type 2 Diabetic

Figure1. Type 1 & Type 2 Diabetic

Figure 2 shows the percentage of the A1c, Fasting Plasma Glucose and Oral Glucose Tolerence test in the measure of both mg/dl and mmol/l. The level of the glucose is increased from the bottom level to higher level. The bottom level shows the healthy body and top shows diabetes.



Nature of the Body	A1c (%)	Fasting Plasma Glucose		Oral Glucose Tolerance Test	
		mg/dl	mmol/l	mg/dl	mmol/l
Diabetes	6.5 & above	126 & above	7 & above	200 & above	11.1 & above
Pre Diabetes	5.7 to 6.4	100 to 126	5.56 to 7	140 to 199	7.77 to 11
Healthy	Below 5.6	99 & below	3.89 & 5.5	139 & below	7.72 & below

Figure2. Level of Glucose for the Diabetes

Foot Ulcer and its Types

The increasing level of glucose may cause many problems in the human body. This paper mainly concentrates on the problems caused in the blood vessels and nerves. This problem sometimes leads to foot ulcer in the body. Poorly controlled diabetic is the main reason for foot ulcer. This problem slowly affects the feet down to the bones. Foot ulcer is a crater on the skin in red colour. The poor circulation of the blood, damages the blood vessels and nerves. These are the most common attributes of foot ulcer. It is a wound that will not heal or keep returning. Figure 3 shows the different stages of Foot Ulcer in which, the severity level of ulcer is increased from stage 1 to stage 4. Stage 1 is having the less severity and the stage 4 is having the more severity. The Stage 3 and 4 are more dangerous, if it is not diagonised properly. These stages leads to leg dismissal of the patient.

Figure3. Different Stages of Foot Ulcer

Nearly 25% of the patients with diabetes are having the problem of foot ulcer and this problem leads to impairment and leg confiscation. It is estimated that, in every 30 seconds one patient is having the problem of leg elimination [2]. Early detection and proper classification of foot ulcer gives the valuable life to many people throughout the world and it gives better ideas for practitioners to treat in the way of follow up. As per the Cleveland clinic report, the foot ulcer is classified into Venous stasis ulcers, Neurotrophic (Diabetic), and Arterial (ischemic ulcers) based on the factors like location in the body, appearance, patient history.

The venous stasis ulcers is red in colour, may be found in the inner side of the leg and below the knee. The affected people may already have any one or every one of the following problems: blood clots, varicose veins and leg swelling. Neurotropic is an ulcer based on the diabetic. It is in pink or red colour, the location base varies depending on the circulation. But the most common location for this ulcer is pressure point on the bottom of the feet. The main symptoms of neuropathy are burning, tingling and numbness. The arterial ulcer is on the feet and between the toes. It is in black, brown or yellow colour. People those who are having poor circulation, may lead to this ulcer [3]. Within this classification, the Neuropathic ulcer, Ischemic ulcer is based on the diabetic ulcer and it is also having the Neuro ischemic ulcer. The peripheral diabetic neuropathy is a 90% of factor for Neuropathic ulcer. Nerves are damaged because of higher range of glucose or sugar levels in the body. This will lead to the problem of autonomic, sensory and motor of the nerves. It also causes weakness in muscles, reduces the sensation and loss of reflexes. The peripheral artery is the most important factor for the ischemic ulcers. Peripheral artery disease (PAD) is the poor circulation, will affect the veins of the hand and also the feet. Neuro ischemic ulcer is the combination of both Neuropathic ulcers and Ischemic ulcer [4]. This paper mainly concentrates on the classification of diabetic foot ulcer for the efficient treatment of the patient. This classification will be performed by using Machine Learning Algorithms.

Classification Techniques

The various techniques of machine learning are Supervised Learning, Unsupervised learning and Reinforcement learning. This learning is mainly based on the training and testing of algorithms. In supervised learning, the class label of the particular data is provided to the machine and based on this, label training is performed. But, in unsupervised learning this class label is not provided to the machine. Here, the machine is going to be trained based on their previous knowledge about the data. Reinforcement learning is the environment based learning. Based on the environmental factor, the machine is trained. Figure 4 shows the

architecture of the classification system. The classification is having the following steps: Feature Extraction, Feature Selection and finally classification.

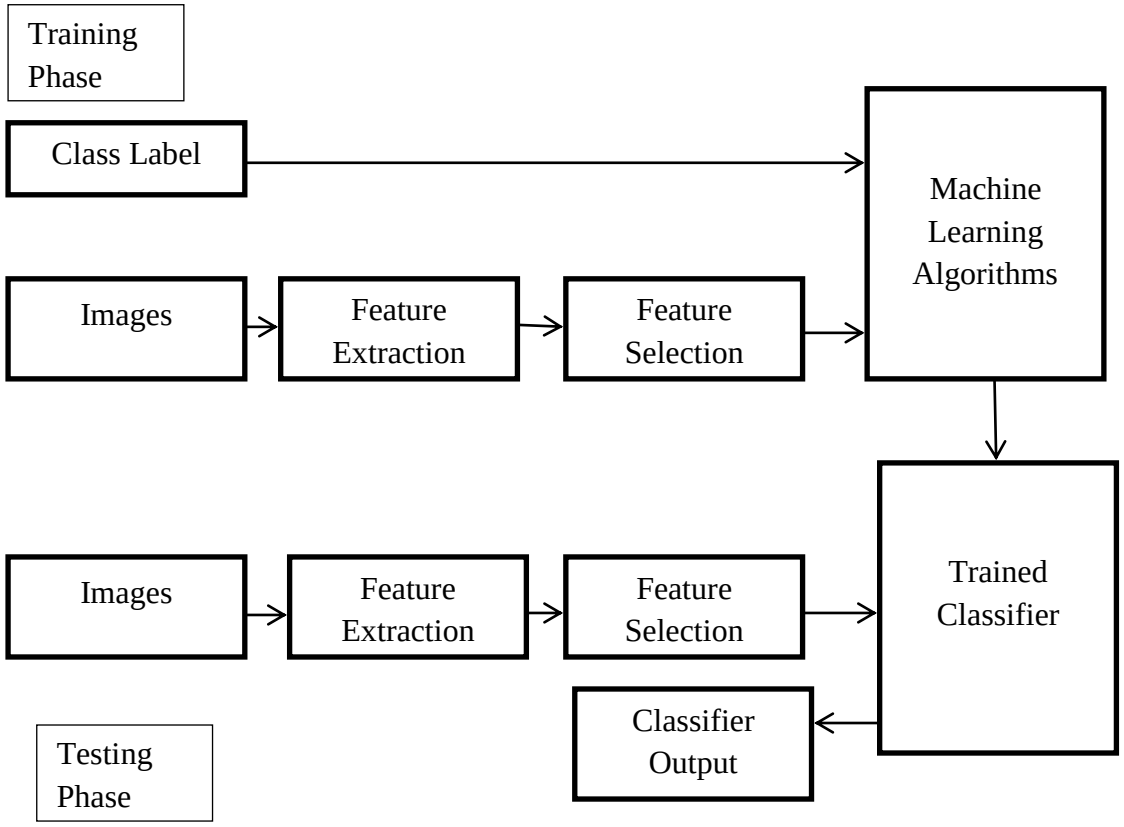


Figure4. Architecture of the Classification System

Here, the images are considered as the input for classification. In feature extraction, the attributes of the images are extracted. After the extraction, the features are passed into feature selection to select the high impact features needed for the classifier. This feature selection process in mainly used to improve the performance of the classifier. Based on the error rate or accuracy, the classifier is tuned to get better output. The commonly used classifier algorithms are Decision tree Classifier, Random Forest, Naïve Bayes, Support Vector Machine (SVM), and Neural Network based classifier. The next chapter gives a detailed survey on various types of machine learning classification algorithms. Based on this survey, the best algorithm will be chosen for the future classification work.

Literature Survey

H. Kaur, et.al. 2018 have used many machine learning approaches to predict and analyse the diabetes of patients. This paper used the Pima Indian diabetes dataset for generating the trends and to predict the patterns of diabetic and non-diabetic. It was implemented by using the R-Tool. This approach has used many algorithms such as Artificial Neural Network, K-Nearest Neighbour Classifier, Support Vector Machine(SVM)

for linear, Radial Basis Function (RBF) with SVM and Multifactor Dimensionality Reduction (MDR). It uses different measures to find the best algorithm for this data set. The measures are Accuracy, Recall, Precision and F1 Score. Table 1 shows the value of different measures in which, the SVM-Linear is having the highest accuracy and precision of 0.89, 0.88, KNN having the highest Recall and F1 Score of 0.90, 0.88 [5].

Table1. Evaluation of Different Parameters

S.No.	Predictive models	Evaluation Parameters			
		Accuracy	Recall	Precision	F1 Score
1	SVM –Linear	0.89	0.87	0.88	0.87
2	RBF – SVM	0.84	0.83	0.85	0.83
3	K-NN	0.88	0.90	0.87	0.88
4	ANN	0.86	0.88	0.85	0.86
5	MDR	0.83	0.87	0.82	0.84

The diabetes prediction and prevention is the most interesting topics in today's healthcare industry. SajidaPerveena, et.al. have proposed the J48 classifier algorithm with adaboost and bagging ensemble techniques and standalone J48 classifier. These algorithms were applied to three categories of ordinal adult groups in Canadian surveillance network in which, the adaboost method produced the better performance when compared to bagging and J48 standalone classifier. Gain Ratio is used to find the best features from the 'N' number of features. This paper gives a method to predict the diabetes and non-diabetes based on the age group [6].

Christy Pushpaleela, et.al. did the detailed review on various classification algorithms such as SVM, C4.5 (J48), Decision Tree and the KNN classifier to classify the foot ulcer. In which, the accuracy of these algorithms are 92.22, 85.68, 75.45 and 73.77. This paper stated that, the reason for the foot ulcer is Nerve Damage, High Blood Sugar, Irritated or Wounded Foot and Poor Circulation. This implementation is done using the Weka tool [7].

Aymen Ahmad Khan, et.al reviewed the World Health Organization (WHO) report published by 2013. In that, currently in India 65.1 million people affected by the diabetes and in future it is expected to 142.7 million by 2035. The patient affected by foot ulcer is in the age group of 56-65 years. From that, the ratio of male and female was 1.4:1 [8].Manu Goyalet,al., have introduced the Fully convolutional Networks for foot ulcer segmentation. This paper is focused to reduce the cost of diagnosis in the form of proper segmentation. For the ground truth, it was used 705 images with 5-fold cross validation and it used the two tier

transfer learning to train the FCN. Dice Similarity Co-efficient of FCN for ulcer region is 0.794 (±0.104), skin region and combination of both the regions are 0.851 (±0.148), 0.899 (±0.072) [9]. The diabetes range have been increased from 4,7% to 8.5% among the adults.

KalpnaGuleria et.al.used the supervised learning algorithms such as Random Forest, Gradient Boosted Tree and Tree Ensemble to produce the predictive models. These algorithms are implemented using Pima Indian Diabetic dataset. Here the Random Forest having the highest accuracy of 75.32%, Naïve Bayes is 74.45%, Decision Tree is 68.39%. The highest F-measure is also for the Random forest with 0.81672 for negative and 0.6225 for positive class respectively[10].

The Deep Convolutional Neural Network (DCNN) is used for the classification of skin with foot ulcer. It produced the cost effective and efficient approach for the classification. DCNN is used for feature extraction and these features are trained using SVM and KNN classifier. These algorithms are compared with the GoogleNet, VGG16, and AlexN. In which, the DCNN had the highest accuracy of 94.45% [11]. The wound region of foot ulcer is classified using the Support Vector Machine, K-Nearest Neighbor classifier, Bayesian Netwoks, Fuzzy logic and Neural Networks. It used the following steps for classification: Pre-processing, Image Segmentation, Feature Extraction and Texture Detection and finally classification [12].

Yun-lei Sun have reviewed the supervised, unsupervised learning and deep learning Networks for Screening and Diagnosis of Diabetes. In the survey it uses the attributes such as body mass index (BMI), sex, race/ethnicity, age, medication records, haemoglobin disease/anaemia, cardiovascular disease and family history. It uses the different data set like DiScRi, PPI, Neuro, GEO, DGAP, and PIMA [13]. Manu Goyal et.al. had proposed the Novel Convolutional Neural Network to extract the features for healthy skin and affected skin. With the 10 fold cross validations, the proposed N-CNN gives an AUC score of 0.961, which is the improvised outcome of both the traditional Machine learning and Deep learning classifiers [14].

Lei Wang et.al. designed a wound evaluation system to assist the patients having foot ulcers to identify it visually and measuring manually. For evaluating the system, 12 patient's data from the University of Massachusetts Medical School had been considered. The validity of the proposed healing score algorithm ranges between 0.42 and 0.81, which indicates that the proposed method is a time efficient one [15]. T. Santhanam et.al. did an analysis for reducing the dimensions by integrating SVM for diagnosing diabetes. In the research, K-Means was used to remove the noise in the data and the Genetic algorithm along with SVM

was used for classification. This paper used the Pima Indians Diabetes dataset from UCI repository. The proposed method has an accuracy of 98.79% which has an increase of 2.08% over the modified K-Means and SVM [16].

Manu Goyal et.al. designed a deep learning method for real time diabetic foot ulcer detection. For the ground truth, a wide-ranging database of 1775 DFU images were used with 5-fold cross validation. The proposed Faster Regions -CNN with Inception V2 model using 2-tier transfer learning produced a precision of 91.8%. The performance was evaluated using NVIDIA Jetson Tx2 and in smart the phone app [17]. Shahabeddin Abhari et.al.aimed to determine the AI applications for the type 2 diabetes. The author did a detailed review using the datasets from PubMed, Web of Science and Embase Scientific databases based on Preferred Reporting Items for Systematic Reviews and Meta Analysis. The machine learning methods were found to be most commonly used technique. Among the ML algorithms, SVM and Naive Bayes are the most frequently used techniques. The attributes used in the survey were BMI, fasting blood sugar, blood pressure, HbA1c, triglycerides, low and high density lipoprotein [18].

Prasad Umesh Kasbekar et.al. created an evidence based tool, which guides the diabetic foot patients who are at the risk of amputation. This paper used the hospital records of 301 diabetic foot patients for explanatory variables of poor amputation decisions. The dataset was analyzed using decision tree algorithm and C5.0. The results obtained for decision tree algorithm are 96.4% and 94% in the primary group and test group respectively. Similarly, the C5.0 shows an accuracy of 100% in the principle group and 96% during testing. Therefore, these two classifications were used to predict the risk of future amputation in patients with diabetic foot ulcer [19]. D. Hernandez Contreras et.al. introduced a new public planter thermogram dataset to study the complications in diabetic foot ulcer. The dataset composed of 334 individual planter images collected from 122 diabetic and 45 non-diabetic subjects. The work was carried out expecting to provide a valuable way for the early detection of diabetes among people. The author also reviewed the various techniques of segmentation, registration, and correction of foot posture [20].

Liela Yazdanpanah et.al. 2015, did a detailed review on the early effective management of diabetic foot ulcer to reduce the mortality rate based on National Institute for Health and Clinical Excellence strategies. The author considered the datasets available from PubMed, Science Direct, Embase, Web of Science and Scopus for the review. The various attributes taken into account are, blood sugar control, wound debridement, advanced dressings, and offloading modalities. It was concluded that, with the suitable patient

education, 50% of the DFU complications can be prevented [21]. Arianna Dagliati et.al. developed an algorithm that learn patterns and decision rules from the available data. Here, the ML algorithms have been merged with the data mining pipelines, which can combine the classical statistical strategies to extract information from the data. The author used logistic regression with stepwise feature selection to identify the onset of retinopathy, neuropathy and nephropathy. The variables considered are gender, age, body mass index, time of diagnosis, glycated haemoglobin and smoking behaviour. The proposed model provides an accuracy of 0.838. [22].

The presence of bacteria in the wound (infection) and inadequate blood supply (ischaemia) in the DFU plays a vital role in DFU assessment which in turn predicts the risk of amputation. Here, a new database with computer vision method was used to identify the bacterial infection and blood supply. The handcrafted ML approach has been achieved by a new feature descriptor called Superpixel Color Descriptor. The proposed Ensemble CNN deep learning algorithm performed better with 90% accuracy in ischaemia classification and 73% in infection classification. Table 2 shows the performance measure of both ischaemia and infection classifications using the Ensemble CNN approach [23].

Table 2. Performance measure of Ischaemia and Infection [23].

Factors	Accuracy	Sensitivity	Precision	Specificity	F-Measure	MCC Score	AUC Score
Ischaemia	0.903±0.012	0.886±0.035	0.918±0.019	0.921±0.021	0.902±0.014	0.807±0.022	0.904
Infection	0.727±0.025	0.709±0.044	0.735±0.036	0.744±0.050	0.722±0.028	0.454±0.052	0.731

Israel Cruz Vega et.al. 2019, compared the Machine Learning based technique with Deep Learning structures. Here, the conventional classifiers like ANN, SVM, and CNNs like GoogleNet and AlexNet were compared and the result obtained was found to be less. So, the DL structures are combined with ML techniques to avoid the exhaustive task of feature extraction and segmentation. The proposed DFTNet provides better results in all aspects of sensitivity, specificity, accuracy, and AUC values among other methods [24]. A new computer assisted tissue classification including granulation, necrotic, and slough method for chronic wound evaluation has been developed. For the analysis, the image captured from the normal camera was converted into HSI (Hue, Saturation, and Intensity) color space and CW

wound were segmented using the Fuzzy divergence based thresholding method. Various mathematical techniques were used to extract the texture feature and color for describing granulation, necrotic, and slough. The Bayesian classification and SVM techniques were used to validate the ground truth images. It was found that SVM provides the highest accuracies, (i.e.), 86.94 % for granulation, 90.4% for slough, and 75.53% for necrotic tissues [25].

Dataset Description

The data set for the diabetic foot ulcer consists of 10 attributes with 748 tuples. The major attributes are Glucose, Blood Pressure, Skin Thickness, Range of the Insulin, BMI,Pedigree, Age, Diabetic, Peripheral Neuropathy and Circulatory Problem. This data set is referred from the kaggle website for diabetes. The sample dataset is shown in table 3.

Table3. Sample Data set for Diabetic Foot Ulcer

Glucose	BloodPressure	Skin Thickness	Insulin	BMI	Pedigree	Age	Diabetic	Peripheral Neuropathy	Circulatory Problem
148	72	35	0	33.6	0.627	50	1	1	1
85	66	29	0	26.6	0.351	31	0	0	0
183	64	0	0	23.3	0.672	32	1	0	1
89	66	23	94	28.1	0.167	21	0	0	0
137	40	35	168	43.1	2.288	33	1	1	0
116	74	0	0	25.6	0.201	30	0	0	0
78	50	32	88	31	0.248	26	1	0	0
115	0	0	0	35.3	0.134	29	0	0	0
197	70	45	543	30.5	0.158	53	1	0	1
125	96	0	0	0	0.232	54	1	1	1
110	92	0	0	37.6	0.191	30	0	0	1
168	74	0	0	38	0.537	34	1	0	1
139	80	0	0	27.1	1.441	57	0	0	0
189	60	23	846	30.1	0.398	59	1	1	1
166	72	19	175	25.8	0.587	51	1	0	1
100	0	0	0	30	0.484	32	1	1	1
107	74	0	0	29.6	0.254	31	1	0	0
118	84	47	230	45.8	0.551	31	1	1	1
103	30	38	83	43.3	0.183	33	0	0	0
115	70	30	96	34.6	0.529	32	1	1	1
126	88	41	235	39.3	0.704	27	0	0	0
99	84	0	0	35.4	0.388	50	0	0	0
196	90	0	0	39.8	0.451	41	1	1	1
119	80	35	0	29	0.263	29	1	1	1
143	94	33	146	36.6	0.254	51	1	1	0
125	70	26	115	31.1	0.205	41	1	0	1
147	76	0	0	39.4	0.257	43	1	0	1
97	66	15	140	23.2	0.487	22	0	0	0
145	82	19	110	22.2	0.245	57	0	0	0

Implementation of Classification Algorithms

This paper uses the different algorithms such as Decision Tree, Random Forest, M5 tree model, Random Tree, REP Tree, Neural Networks, ZeroR, Naïve Bayes, Back Propagation Neural Network and Linear Regression model. These algorithms are implemented using Weka and R tool. Attribute range for the different attributes are shown in Figure 5 using the Weka tool.

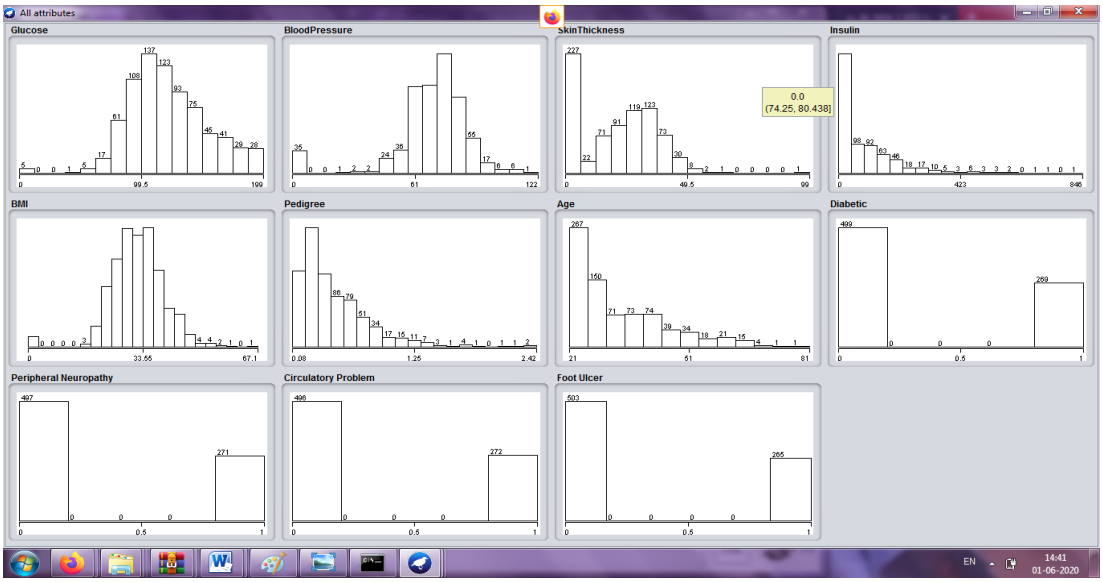


Figure 5. Attributes Range in the Data set

Table4. Classification Algorithms with its Error Rate

S.No.	Algorithms	Execution Time (in secs)	MAE	RMSE	RAE	RRSE
1	Decision Tree	0.17	0.0004	0.0039	0.0799 %	0.8173 %
2	Random Forest	0.44	0.0076	0.0232	1.6877 %	4.8996%
3	M5 Model	0.33	0.0056	0.0141	1.2383 %	2.9718 %
4	Random Tree	0.01	0.0043	0.0658	0.9589 %	13.8692 %
5	REP Tree	0.03	0.0019	0.0023	0.42 %	0.4928 %
6	Neural Networks	0.97	0.0064	0.0309	1.4284 %	6.5092 %
7	Linear Regression Model	0.04	0.0143	0.022	3.1634 %	4.6293 %
8	ZeroR	0.1	0.4514	0.4744	100%	100%

Results ad Discussion:

Results of the various classification algorithms with its error rate are shown in Table 4. The performances of these algorithms are evaluated using the error rate of MAE, RMSE, RAE, RRSE and its execution time. The execution time and its different error rate obtained on the kaggle dataset are as follows. Random Forest: 0.44, 0.0076, 0.0232, 1.6877%, 4.8996%, M5 Model: 0.33, 0.0056, 0.0141, 1.2383%, 2.9718%, Random Tree: 0.01, 0.0043, 0.0658, 0.9589%, 13.8692%, REP Tree: 0.03, 0.0019, 0.0023,0.42%, 0.4928%, Neural Networks: 0.97, 0.0064, 0.0309, 1.4284%, 6.5092%, Linear Regression: 0.04, 0.0143, 0.022, 3.1634%, 4.6293%, ZeroR: 0.1, 0.4514, 0.4744, 100%, 100%. As far as the choice of classification algorithms are concerned, execution time and the error rate is less for decision tree.

Conclusion

Millions of people have been affected by the diabetes disease all over the world. The rate of this disease is steadily increasing every day. Because of diabetes, most of the people have been affected by diabetic foot ulcer. Early detection and classification of foot ulcer is a very important process to give the better treatment. This process of detection and classification is a very interesting research in machine learning. Here, many classification algorithms are reviewed. Of which, the Decision tree has less error rate when compared to other algorithms. The error rates of decision tree are as follows: MAE is 0.0004, RMSE is 0.0039, RAE is 0.0799% and the RRSE is 0.8173.

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