ENHANCING HEART ATTACK PREDICTION ACCURACY BY FINDING BEST SVM PARAMETER VALUE WITH FUZZY LOGIC

A THESIS

A Partial Requirement to Fulfill for Master Degree in Computer Science

ADHI KRISTIANTO

NIM: 20210130014

Supervisor:

Dr. Umar Aditiawarman

Prof. Dr. Teddy Mantoro, MSc., PhD., SMIEEE

SCHOOL OF COMPUTER SCIENCE

NUSA PUTRA UNIVERSITY

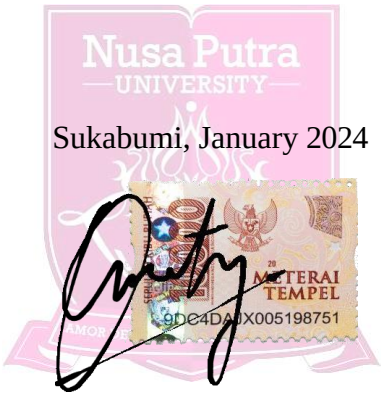
2023

DECLARATION

Title of Thesis: ENHANCING HEART ATTACK PREDICTION ACCURACY BY FINDING BEST SVM PARAMETER VALUE WITH FUZZY LOGIC

"I have read and understood the regulations of Nusa Putra University concerning plagiarism. I here by declare that this submission is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person nor material which has been accepted for the award of any other degree or diploma of the university or other institute of higher learning, except where due acknowledgment has been made in the text."

Sukabumi, January 2024



ADHI KRISTIANTO

20210130014

THESIS APPROVAL

Title: ENHANCING HEART ATTACK PREDICTION ACCURACY BY FINDING BEST SVM PARAMETER VALUE WITH FUZZY LOGIC

Name: Adhi Kristianto

NIM: 20210130014

This thesis has been approved for submission by

Sukabumi, January , 2024

Supervisor 1,

Dr. Umar Aditiawarman
NIDN.012020008

Examiner 1

Dr.Deshinta Arrova Dewi
NIDN.0416127102

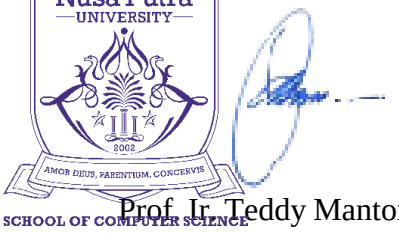
Supervisor 2,

Prof. Ir. Teddy Mantoro, M.Sc., PhD
NIDN.012020006

Examiner 2

Dr. Rahmadya Trias Handayanto, Ph.D
NIDN.012020008

Head of the Study Program



Prof. Ir. Teddy Mantoro, M.Sc., PhD
NIDN. 012020006

THESIS CONFIRMATION

Title : ENHANCING HEART ATTACK PREDICTION ACCURACY BY FINDING BEST SVM PARAMETER VALUE WITH FUZZY LOGIC

Name : Adhi Kristianto

NIM : 20210130014

This thesis has been presented to and examined by the examination board in January 2024, and has been confirmed to be satisfactory for the degree of Master in Computer Science.

Sukabumi, January 2024

Supevisor I,	Chair of the examination board
Dr Umar Aditiawarman	Dr Deshinta Arrova Dewi
NIDN.012020008	NIDN. 0416127102

Head of the Study Program

Prof. Ir. Teddy Mantoro, M.Sc., PhD
NIDN. 012020006

PUBLICATION CONSENT

As a member of the academic community of Nusa Putra University, I undersigned:

Name: Adhi Kristianto

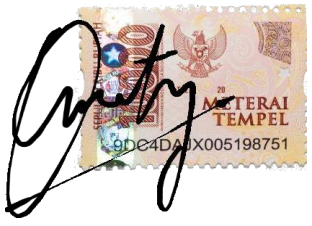
ID of Student: 20190130012

Study Program: Computer Science

Type of Work: Thesis

For the purpose of scientific development, agree to grant to the Nusa Putra University the Non-Exclusive Royality-Free Right for my scientific work entitled: ENHANCING HEART ATTACK PREDICTION ACCURACY BY FINDING BEST SVM PARAMETER VALUE WITH FUZZY LOGIC, along with existing devices (if applicable). With this non-exclusive royalty-freeright, Nusa Putra University has the right to store, transfer media/formats, process in the form of a database, maintain and publish my thesis as long as I keep my name as the author/creator and as the copyright owner.

Sukabumi, 24 January 2024



(Adhi Kristianto)

Table of Content

LIST OF TABLES

LIST OF FIGURES

LIST OF GRAPHS

FOREWORD

Praise and gratitude the author prays to Allah Subhanahu Wata'ala, God of Almighty, because only with His blessings and grace can the author complete this thesis. Greetings to the Prophet Muhammad, Shallallahu 'Alaihi Wasallam. The last prophet and the best human ever born on earth. Writing this thesis is one of the requirements to achieve a Master's degree in Computer Science at Nusa Putra University. I realize that, without the help and guidance of various parties, from thelecture period to the preparation of this thesis, it is very difficult for the author to complete this thesis. Therefore, I would like to thank:

1. Dr. Kurniawan, ST., M.Sc., MM as Chancellor of Nusa Putra University.
2. Prof. Ir. Teddy Mantoro, M.Sc., PhD as Head of School Computer Science Nusa Putra University and Supervisor 2; and Dr Umar Aditiawarman as Supervisor 1.
3. Deshinta Arrova Dewi S.Kom, M.Si, PhD and Rahmadya Trias Handayanto ST, M.Kom, PhD as Examiner.
4. All Master of Computer Science Lecturers who have provided very usefull knowledge during lectures. Fellow comrades in Master of Computer Science 2021 who always give encouragement and always accompany from the beginning of the lecture until now.
5. Parents, beloved wife Dina Farihani and my childrens (Faatih, Fathina, Fawzan, Faris, Feisya and Faqih) for their suppors, patience, prayers and never getting tired of educating and giving, bothmaterial and non-material.
6. All parties who have helped the author in writing this thesis.

For further improvement, suggestions and constructive criticism will be gladly accepted.

Sukabumi, January 2024

Writer

ABSTRACT

Cardiovascular disease (CVD) is still one of the highest causes of death in the world. One of them is heart disease. It is important to detect heart disease as early as possible so that management with counselling and medicines can begin as soon as possible. Delayed diagnosis will lead to increased morbidity and mortality in patients. However, detecting heart disease at an early stage is not easy, so getting accurate predictions will really help patients get treatment more quickly. Making accurate predictions is a challenge considering the large amount of data that must be processed. One prediction method that can be used is the use of the SVM machine learning algorithm. The use of the SVM algorithm in making predictions cannot be separated from finding a hyperplane that can separate the existing feature set maximally. This research will use Fuzzy Logic to find the best SVM parameter value, so that the resulting hyperplane can be maximized and can provide better prediction results. This sutdy use Heart Disease Classification Dataset from Kaggle, which consists of 1.319 data that has eight input fields and one output field. Results of prediction heart attack risk from standard SVM shows 80% of whole accuracy with 73% precission for negative class and 83% precission for positive class. The whole process takes 1.362 seconds to finish. Results of prediction by using SVM with best prameter value from fuzzy logic give 89.39% whole accuracy, 85% precission for negative class and 92% precission for positive class. The whole process takes 1 minute 10 seconds to finish using all the computer CPUs. This research shows that using fuzzy logic to find the best SVM parameter value can improve the performance of the SVM algorithm in predicting heart attacks.

Keywords— enhancing prediction, cardio vascular disease, fuzzy logic, SVM

CHAPTER I
INTRODUCTION

I.1 Research Background

Cardiovascular diseases (CVDs), caused by disorders of the heart and blood vessels, is still one of the highest causes of death in the world. An estimated 17.9 million people died from CVDs in 2019, representing 32% of all global deaths. Of these deaths, 85% were due to heart attack and stroke (World Health Organization, 2021). In Indonesia, deaths caused by heart-related diseases are also among the highest in many years (THE INSTITUTE FOR HEALTH METRICS AND EVALUATION, 2023).

With a high death rate, it is important to detect cardiovascular disease as early as possible so that management with counselling and medicines can begin as soon as possible. But according to (Groenewegen et al., 2021), diagnosing non-acute cardiovascular diseases (CVDs) in an early stage may be difficult because symptoms can be non-specific or atypical. Diagnosis made by asking the patient directly is not always accurate because the symptoms of the disease may not be realized or felt by the patient. Meanwhile, to be able to prevent the risk of more serious disease, early detection needs to be carried out. Early detection of the risk of having a heart attack will be very useful because it can be the basis for appropriate education and intervention for patients, so that the opportunity to reduce the risk of having a heart attack becomes greater. So, methods other than directly diagnosing patients are needed.

One method that can be used is to predict the possibility of contracting a cardiovascular disease (CVDs), in this case heart attack, is by utilizing a dataset from patients who have had a previous diagnosis.

Getting accurate predictions is challenging with the amount of data that must be processed. One prediction method that can be used is the use of the SVM machine learning algorithm.

The use of the SVM algorithm in making predictions cannot be separated from finding a hyperplane that can separate the existing feature set maximally. To find the best hyperplane, which can separate the existing feature set maximally, parameter values are needed from the appropriate SVM algorithm, known as hyperparameters. These parameters include the value of the regularization parameter, the value of the kernel coefficient and the type of SVM kernel used (Aqsa Qadir, 2020). But according to (Gupta & Goel, 2023), finding the optimum results through different parameter values is a very difficult task.

Given the complexity of selecting the optimal prediction model for a particular data set from a wide collection of prediction methods and the different hyperparameter values per model, the use of fuzzy logic is expected to improve prediction accuracy. Studies have shown that fuzzy logic methodologies can be utilized in early diagnosis of diseases such as Parkinson's disease (Elena Vlamou & Basil Papadopoulos, 2019).

This research will use Fuzzy Logic to find the best parameter value, so that the resulting hyperplane can be maximized. So that later, the prediction results from the SVM algorithm used can provide better prediction results.

I.2 Problem Statement

Diagnosing non-acute heart disease in an early stage may be difficult because symptoms can be non-specific or atypical. Diagnosis made by asking the patient directly is not always accurate because the symptoms of the disease may not be realized or felt by the patient. Delayed diagnosis would lead to excess morbidity and mortality for the patient. This delayed diagnose is due to, according to (Hobbs, 2000), difficult condition to diagnose clinically. Where in the same study said that, only 32% of patients suspected of having heart failure by primary care doctors had definite heart failure.

Getting accurate predictions is challenging with the amount of data that must be processed. One prediction method that can be used is the use of the SVM machine learning algorithm. The SVM performance highly depends on parameter setting and its kernel selection, and the selection quality of SVM parameters and kernel

functions have an effect on the learning and generalization performance. But according to (Gupta & Goel, 2023), finding the optimum results through different parameter values is a very difficult task.

I.3 Solution to the Problem

A feasible solution to solve this problem is to address key inquiries related to the prediction of heart attack risk utilizing the Support Vector Machine (SVM) machine learning algorithm. Referring to the statement that the quality of SVM parameter selection and kernel function influences learning and generalization performance, it is important to seeks to optimize its performance through the utilization of fuzzy logic for parameter value tuning.

According to (Elena Vlamou & Basil Papadopoulos, 2019), studies have shown that fuzzy logic methodologies can be utilized in early diagnosis of diseases. Other study explained that the fuzzy logic with Multi-class Support Vector Machine method is effective in selection of the rules to make decision (Devi Thangavel et al., 2023) and the combined method of fuzzy with SVM has the least amount of error.

I.4 Research Objectives

- To explore the machine learning algorithm SVM in prediction of heart disease risk.
- To evaluate and compare the accuracies of various parameters value of machine learning algorithm SVM in predicting heart disease risk.
- To optimize the machine learning algorithm SVM performance in prediction of heart disease risk through the utilization of fuzzy logic for parameter value tuning.
- To find the best parameter value for machine learning algorithm SVM in predicting heart disease risk by using fuzzy logic.

I.5 Research Questions

RQ 1: How to use SVM machine learning to predict heart disease risk?

RQ 2: Can fuzzy logic optimize the performance of SVM learning machines in predicting heart disease risk?

RQ 3: What is the level of accuracy of SVM learning machine predictions in predicting the risk of heart disease with and without the use of fuzzy logic?

I.6 Significance of Research

Various uses of machine learning in the medical world to predict certain diseases, one of which is the risk of heart disease, have been presented in recent years. For example, research on the use of machine learning to improve early diagnosis of cardiovascular disease (Groenewegen et al., 2021); ASP machine learning-based CVD prediction (Sun et al., 2021); heart disease prediction with Fusion-Based Machine Learning Architecture (Waqas Nadeem et al., 2021), and many more. But, before this research was carried out, research regarding methods for increasing the prediction accuracy of SVM learning machines using fuzzy logic in the medical field, especially in predicting the risk of heart disease, was not found much. Therefore, this research can become a better heart attack risk prediction accuracy model through the use of fuzzy logic in finding the best SVM machine learning algorithm parameter value. It is hoped that this research will provide benefits through early detection of the risk of heart attacks so that patients can be given preventive and early intervention effort.

I.7 Limitation of Studies and Assumptions

The problem in the research are limited and assumed to be as follows:

- Focuses on increasing the accuracy of heart attack risk predictions through the use of fuzzy logic in determining the best SVM machine learning algorithm parameter value.
- Compare the level of accuracy of various parameters value of SVM machine learning algorithms in predicting heart attack risk.
- The use of fuzzy logic is assumed to be able to increase the accuracy of predictions by finding machine learning algorithm parameters value that show the highest accuracy.

- The object of research is limited to datasets from Heart Disease Classification Dataset from Kaggle (BHARATH_011, 2023) consists of 1.319 data which has eight input fields and one output field. No data from medical records, doctor's notes, MRI results or other forms of medical data were used in this study.

.

Nusa Putra
UNIVERSITY
2002
AMOR DEUS, PARENTIUM, CONCERVIS

CHAPTER V
CONCLUSION AND FUTURE WORK

V.1 Conclusion

Heart disease risk prediction is an important and challenging task in the medical field. The risk of death from heart disease can be controlled significantly if heart disease is diagnosed early and preventive measures are taken. The prediction process carried out in this research uses the Heart Disease Classification dataset from Kaggle and provides the following description of the results:

- Prediction process the dataset divided into two types, training data and test data. In this research, the amount of training data is 80% of all data, which is 1.055 data, and the remaining 20%, which is 264 data, is the test data.
- Results of prediction heart attack risk from the standard SVM shows 80% of whole accuracy, 73% precission for negative class, and 83% precission for positive class. From the confussion matrix, it shows that standard SVM gets 74 True Negative, 27 False Positive, 27 False Negative and 136 True Positive and the whole process takes 1.362 seconds to finish.
- Result of prediction by using SVM with best parameter value from fuzzy logic show that when C=435 and using linear kernel, gives higher accuracy rate. Which give 89.39% whole accuracy, 85% precission for negative class and 92% precission for positive class. From the confussion matrix, we can see that SVM with best parameter value from fuzzy logice gets 88 True Negative, 15 False Positive, 13 False Negative and 148 True Positive and the whole process takes 1 minute 10 seconds to finish using all the computer CPUs.

We can see that using fuzzy logic to find the best parameter value for SVM can improve the performance of the SVM algorithm in predicting heart attacks. A nearly 10% of increase, from 80% when using the SVM standard to 89.39%, will certainly make a significant contribution to helping patients get care or treatment as early as possible. Thus, the risk of death from heart disease can be reduced.

V.2 Future Work

In recent years, machine learning methods and techniques have achieved effective performance in processing raw data so that they can provide information regarding the risk of heart disease. Nevertheless, existing machine learning methods have some limitations in terms of accuracy.

This study has certain limitations that must be noted. Although there was an 9.39% increase in predictions overall, the time required to generate prediction reports also increased. From only 1,362 seconds to produce a report using standard SVM, to 1 minute 10 seconds when using SVM using best parameter value from fuzzy logic. This can of course become an obstacle when the dataset used is larger, or there are more parameter values entered into the grid parameters.

With better prior knowledge of the dataset and other informations that discussed in this study, definition of param grid values can be optimized to get better and faster result. Using different dataset might also give us different results.

In addition, in order to increase the level of prediction accuracy to a higher level, further research can use a variety of different or more diverse machine learning algorithms.

Bibliography

Alamsyah, A., & Fadila, T. (2021). Increased accuracy of prediction hepatitis disease using the application of principal component analysis on a support vector machine. *Journal of Physics: Conference Series*, *1968*(1), 012016. https://doi.org/10.1088/1742-6596/1968/1/012016

Aqsa Qadir. (2020, March 18). *Tuning parameters of SVM: Kernel, Regularization, Gamma and Margin*. 2023. https://aqsa-qadir44.medium.com/tuning-parameters-of-svm-kernel-regularization-gamma-and-margin-5f2f6639121a

Bernhard E. Boser, Isabelle M. Guyon, & Vladimir N. Vapnik. (n.d.). *Support Vector Machines*. https://doi.org/https://doi.org/10.1007/978-0-387-30162-4_415

BHARATH_011. (2023, October 30). *Heart Disease Classification Dataset*. Https://Www.Kaggle.Com/Datasets/Bharath011/Heart-Disease-Classification-Dataset/Data.

Candelieri, A., Giordani, I., Archetti, F., Barkalov, K., Meyerov, I., Polovinkin, A., Sysoyev, A., & Zolotykh, N. (2019). Tuning hyperparameters of a SVM-based water demand forecasting system through parallel global optimization. *Computers & Operations Research*, *106*, 202–209. https://doi.org/10.1016/j.cor.2018.01.013

Chang, C.-C., & Chou, S.-H. (2015). Tuning of the hyperparameters for L2-loss SVMs with the RBF kernel by the maximum-margin principle and the jackknife technique. *Pattern Recognition*, *48*(12), 3983–3992. https://doi.org/10.1016/j.patcog.2015.06.017

Chowdhury, D., & Hovda, S. (2023). A hybrid fuzzy logic/genetic algorithm model based on experimental data for estimation of cuttings concentration during drilling. *Geoenergy Science and Engineering*, *231*, 212387. https://doi.org/10.1016/j.geoen.2023.212387

Crone, S. F., Lessmann, S., & Stahlbock, R. (2006). The impact of preprocessing on data mining: An evaluation of classifier sensitivity in direct marketing. *European Journal of Operational Research*, *173*(3), 781–800. https://doi.org/10.1016/j.ejor.2005.07.023

Czarnecki, W. M., Podlewska, S., & Bojarski, A. J. (2015). Robust optimization of SVM hyperparameters in the classification of bioactive compounds. *Journal of Cheminformatics*, *7*(1), 38. https://doi.org/10.1186/s13321-015-0088-0

Devi Thangavel, K., Seerengasamy, U., Palaniappan, S., & Sekar, R. (2023). Prediction of factors for Controlling of Green House Farming with Fuzzy based multiclass Support Vector Machine. *Alexandria Engineering Journal*, *62*, 279–289. https://doi.org/10.1016/j.aej.2022.07.016

Duan, K., Keerthi, S. S., & Poo, A. N. (2003). Evaluation of simple performance measures for tuning SVM hyperparameters. *Neurocomputing*, *51*, 41–59. https://doi.org/10.1016/S0925-2312(02)00601-X

Elena Vlamou, & Basil Papadopoulos. (2019). Fuzzy logic systems and medical applications. *AIMS Neuroscience*, *6*(4), 266–272. https://doi.org/10.3934/Neuroscience.2019.4.266

Friedrichs, F., & Igel, C. (2005). Evolutionary tuning of multiple SVM parameters. *Neurocomputing*, *64*, 107–117. https://doi.org/10.1016/j.neucom.2004.11.022

Gowthul Alam, M. M., & Baulkani, S. (2019). Local and global characteristics-based kernel hybridization to increase optimal support vector machine performance for stock market prediction. *Knowledge and Information Systems*, *60*(2), 971–1000. https://doi.org/10.1007/s10115-018-1263-1

Groenewegen, A., Zwartkruis, V. W., Rienstra, M., Hollander, M., Koffijberg, H., Cramer, M. J. M., van der Schouw, Y. T., Hoes, A. W., de Boer, R. A., & Rutten, F. H. (2021). Improving early diagnosis of cardiovascular disease in patients with type 2 diabetes and COPD: protocol of the RED-CVD cluster randomised diagnostic trial. *BMJ Open*, *11*(10), e046330. https://doi.org/10.1136/bmjopen-2020-046330

Gupta, S. C., & Goel, N. (2023). Predictive Modeling and Analytics for Diabetes using Hyperparameter tuned Machine Learning Techniques. *Procedia Computer Science*, *218*, 1257–1269. https://doi.org/10.1016/j.procs.2023.01.104

Hobbs, F. D. R. (2000). ABC of heart failure: Heart failure in general practice. *BMJ*, *320*(7235), 626–629. https://doi.org/10.1136/bmj.320.7235.626

Indriani, A. F., & Muslim, M. A. (2019). SVM Optimization Based on PSO and AdaBoost to Increasing Accuracy of CKD Diagnosis. *Lontar Komputer : Jurnal Ilmiah Teknologi Informasi*, 119. https://doi.org/10.24843/LKJITI.2019.v10.i02.p06

Jamaleddyn, I., El ayachi, R., & Biniz, M. (2023). An improved approach to Arabic news classification based on hyperparameter tuning of machine learning algorithms. *Journal of Engineering Research*, *11*(2), 100061. https://doi.org/10.1016/j.jer.2023.100061

Kamel, S. R., YaghoubZadeh, R., & Kheirabadi, M. (2019). Improving the performance of support-vector machine by selecting the best features by Gray Wolf algorithm to increase the accuracy of diagnosis of breast cancer. *Journal of Big Data*, *6*(1), 90. https://doi.org/10.1186/s40537-019-0247-7

Kementerian Kesehatan Republik Indonesia. (2022, September 5). *5 Faktor Pemicu Gejala Serangan Jantung*. https://ayosehat.kemkes.go.id/5-faktor-pemicu-gejala-serangan-jantung

Kevin M. Passino, & Stephen Yurkovich. (1997). *Fuzzy Control* (First edition). Addison Wesley Longman, Inc.

Krittanawong, C., Virk, H. U. H., Bangalore, S., Wang, Z., Johnson, K. W., Pinotti, R., Zhang, H., Kaplin, S., Narasimhan, B., Kitai, T., Baber, U., Halperin, J. L., & Tang, W. H. W. (2020). Machine learning prediction in cardiovascular diseases: a meta-analysis. *Scientific Reports*, *10*(1), 16057. https://doi.org/10.1038/s41598-020-72685-1

Kwok, C. S., Burke, H., McDermott, S., Welsh, V., Barker, D., Patwala, A., Duckett, S., Satchithananda, D., & Mallen, C. D. (2022). Missed Opportunities in the Diagnosis of Heart Failure: Evaluation of Pathways to Determine Sources of Delay to Specialist Evaluation. *Current Heart Failure Reports*, *19*(4), 247–253. https://doi.org/10.1007/s11897-022-00551-4

Laanaya, H., Abdallah, F., Snoussi, H., & Richard, C. (2011). Learning general Gaussian kernel hyperparameters of SVMs using optimization on symmetric positive-definite matrices manifold. *Pattern Recognition Letters*, *32*(13), 1511–1515. https://doi.org/10.1016/j.patrec.2011.05.009

Lestari, W., & Sumarlinda, S. (2022). *IMPLEMENTATION OF K-NEAREST NEIGHBOR (KNN) AND SUPORT VECTOR MACHINE (SVM) FOR CLASIFICATION CARDIOVASCULAR DISEASE*. https://archive.ics.uci.edu/ml/datasets/heart+disease.

Li, D.-C., & Liu, C.-W. (2010). A class possibility based kernel to increase classification accuracy for small data sets using support vector machines. *Expert Systems with Applications*, *37*(4), 3104–3110. https://doi.org/10.1016/j.eswa.2009.09.019

Mahfouf, M., Abbod, M. F., & Linkens, D. A. (2001). A survey of fuzzy logic monitoring and control utilisation in medicine. *Artificial Intelligence in Medicine*, *21*(1–3), 27–42. https://doi.org/10.1016/S0933-3657(00)00072-5

Mantovani, R. G., Rossi, A. L. D., Alcobaça, E., Vanschoren, J., & de Carvalho, A. C. P. L. F. (2019). A meta-learning recommender system for hyperparameter tuning: Predicting when tuning improves SVM classifiers. *Information Sciences*, *501*, 193–221. https://doi.org/10.1016/j.ins.2019.06.005

Mantovani, R. G., Rossi, A. L. D., Vanschoren, J., Bischl, B., & de Carvalho, A. C. P. L. F. (2015). Effectiveness of Random Search in SVM hyper-parameter tuning. *2015 International Joint Conference on Neural Networks (IJCNN)*, 1–8. https://doi.org/10.1109/IJCNN.2015.7280664

Pannakkong, W., Thiwa-Anont, K., Singthong, K., Parthanadee, P., & Buddhakulsomsiri, J. (2022). Hyperparameter Tuning of Machine Learning Algorithms Using Response Surface Methodology: A Case Study of ANN, SVM, and DBN. *Mathematical Problems in Engineering*, *2022*, 1–17. https://doi.org/10.1155/2022/8513719

Saltin, B., Hartley, L. H., Kilbom, Å., & Åstrand, I. (1969). Physical Training in Sedentary Middle-aged and Older Men II. Oxygen Uptake, Heart Rate, and Blood Lactate Concentration at Submaximal and Maximal Exercise. *Scandinavian Journal of Clinical and Laboratory Investigation*, *24*(4), 323–334. https://doi.org/10.3109/00365516909080169

Schölkopf, B., & Smola, A. J. (2018). *Learning with Kernels*. The MIT Press. https://doi.org/10.7551/mitpress/4175.001.0001

Setiawan, B., Djanali, S., & Ahmad, T. (2019). Increasing Accuracy and Completeness of Intrusion Detection Model Using Fusion of Normalization, Feature Selection Method and Support Vector Machine. *International Journal of Intelligent*

Engineering and Systems, *12*(4), 378–389. https://doi.org/10.22266/ijies2019.0831.35

Sukeiti, W. W., & Surono, S. (2022). Fuzzy Support Vector Machine Using Function Linear Membership and Exponential with Mahanalobis Distance. *JTAM (Jurnal Teori Dan Aplikasi Matematika)*, *6*(2), 268. https://doi.org/10.31764/jtam.v6i2.6912

Sun, W., Zhang, P., Wang, Z., & Li, D. (2021). Prediction of Cardiovascular Diseases based on Machine Learning. *ASP Transactions on Internet of Things*, *1*(1), 30–35. https://doi.org/10.52810/TIOT.2021.100035

THE INSTITUTE FOR HEALTH METRICS AND EVALUATION. (2023, November 4). *Indonesia | The Institute for Health Metrics and Evaluation*. https://www.healthdata.org/research-analysis/health-by-location/profiles/indonesia

V7 Labs. (2021, December 31). *A Simple Guide to Data Preprocessing in Machine Learning*. https://www.v7labs.com/blog/data-preprocessing-guide

Vapnik, V. N. (2000). *The Nature of Statistical Learning Theory*. Springer New York. https://doi.org/10.1007/978-1-4757-3264-1

Wang, Y., Zhao, M., Han, Y., & Zhou, J. (2017). A Fuzzy Expression Way for Air Quality Index with More Comprehensive Information. *Sustainability*, *9*(1), 83. https://doi.org/10.3390/su9010083

Waqas Nadeem, M., Guan Goh, H., Adnan Khan, M., Hussain, M., Faheem Mushtaq, M., & a/p Ponnusamy, V. (2021). Fusion-Based Machine Learning Architecture for Heart Disease Prediction. *Computers, Materials & Continua*, *67*(2), 2481–2496. https://doi.org/10.32604/cmc.2021.014649

World Health Organization. (2021, June 11). *Cardiovascular diseases (CVDs)*. https://www.who.int/news-room/fact-sheets/detail/cardiovascular-diseases-(cvds)

Zadeh, L. A. (1965). Fuzzy S e t s *. In *INFOR~ATIO~ AND CONTROL* (Vol. 8).

Zadeh, L. A. (1992). Knowledge Representation in Fuzzy Logic. In *An Introduction to Fuzzy Logic Applications in Intelligent Systems* (pp. 1–25). Springer US. https://doi.org/10.1007/978-1-4615-3640-6_1

Zhou, J., Yang, F., & Wang, K. (2015). Fuzzy arithmetic on LR fuzzy numbers with applications to fuzzy programming. *Journal of Intelligent & Fuzzy Systems*, *30*(1), 71–87. https://doi.org/10.3233/IFS-151712