

APPLICATION OF COACTIVE-ANFIS TO PREDICT
MICRO-EDM PERFORMANCES

BY

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degree of Master of Science in Engineering

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ABSTRACT

Micro Electrical Discharge Machining (μ EDM) is one of the most demanding manufacturing processes available today. The selection of μ EDM parameters remains a challenge since it is frequently based on machinist intuition and heuristic approaches. In recent years, soft computing and artificial intelligence have been used to model and predict the μ EDM machining process. However, artificial intelligence has not been established for predicting μ EDM performances based on material properties. Therefore, this research proposed a model that considers the material properties, such as thermal conductivity, melting point, and electrical resistivity. Since μ EDM is a non-linear and stochastic process, Coactive Neuro-Fuzzy Inference Systems (CANFIS) was proposed to model and predict the multiple μ EDM performances on various materials. The material properties, feed rate, capacitance, and gap voltage are the input parameters in a three-level design based on a full factorial experiment. The CANFIS model can accurately predict the material removal rate (MRR), total discharge pulse, overcut, and taperness in a single model. The mean average percentage error (MAPE) from the model prediction for test dataset of various outputs such as MRR, total discharge pulse, overcut and taper angle were found to be 9.5% (90.5% accuracy), 8.9% (91.1% accuracy), 16.9% (83.1% accuracy) and 15.7% (84.3% accuracy) respectively. This research proposes a novel approach in modelling and predicting μ EDM performances by considering workpiece's materials using artificial intelligence.



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خلاصة البحث

تعد عملية التفريغ الكهربائي الصغيرة (μ EDM) واحدة من أكثر عمليات التصنيع المتاحة اليوم تطلبًا. يبقى اختيار معلمات μ EDM في التحدي نظرًا لأنه يعتمد كثيرًا على الحدس الميكانيكي والنهج الاستكشافية. في السنوات الأخيرة، اتسع استخدام الحوسبة اللينة والذكاء الاصطناعي لنمذجة عملية تصنيع μ EDM والتنبؤ بها. ومع ذلك، لم يتم إنشاء الذكاء الاصطناعي للتنبؤ بأداء μ EDM بناءً على خصائص المواد. ولأجل ذلك، يقترح هذا البحث نموذجًا مع مراعاة لخصائص المواد، مثل التوصيل الحراري، ونقطة الانصهار، والمقاومة الكهربائية. نظرًا إلى أن μ EDM عملية غير خطية وعشوائية، فقد تم اقتراح Coactive Neuro-Fuzzy Inference Systems (CANFIS) لنمذجة وتوقع أداء μ EDM المتعدد على مواد مختلفة. خصائص المواد، ومعدل التغذية، والسعة، وفجوة الجهد هي معلمات الإدخال في تصميم ثلاثي المستويات يعتمد على تجربة العوامل الكاملة. كان نموذج CANFIS قادرًا على التنبؤ بدقة بمعلمات أداء μ EDM، وهو معدل إزالة المواد (MRR)، ونبض التفريغ الكلي، والقطر الزائد، والنسيج في نموذج واحد. تم العثور على متوسط خطأ النسبة المئوية (MAPE) من التنبؤ النموذجي لمجموعة بيانات الاختبار من المخرجات المختلفة مثل MRR ونبض التفريغ الإجمالي والقطع الزائد وزاوية الاستدقاق $9,5\%$ ($90,5\%$ دقة) و $8,9\%$ ($91,1\%$ دقة)، $16,9\%$ ($83,1\%$ دقة) و $15,7\%$ ($84,3\%$ دقة) على التوالي. يقترح هذا البحث نهجًا جديدًا في النمذجة والتنبؤ بأداء μ EDM بالالتحاذ في مواد قطعة العمل باستخدام الذكاء الاصطناعي.



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ABSTRACT IN BAHASA MALAYSIA

Mikro Pemesinan Nyahcas Elektrik (μ EDM) adalah merupakan salah satu proses pembuatan yang mendapat permintaan yang tinggi pada ketika ini. Pemilihan parameter μ EDM masih lagi menjadi cabaran kerana ia sering ditentukan berdasarkan gerak hati juruteknik dan pendekatan heuristik yang mencabar untuk dimodelkan. Kebelakangan ini, pengkomputeran lembut dan kecerdasan buatan banyak digunakan untuk memodel dan meramal proses μ EDM. Walau bagaimanapun, kecerdasan buatan belum lagi digunakan untuk meramal prestasi μ EDM berdasarkan kepada sifat bahan. Oleh itu, penyelidikan ini mencadangkan suatu model yang mengambil kira sifat bahan, seperti kekonduksian terma, takat lebur dan daya tahan elektrik. Oleh kerana μ EDM ialah proses yang tidak linear dan stokastik, sistem inferens neuro-kabur koaktif (CANFIS) telah diketengahkan untuk memodel dan meramal pelbagai prestasi μ EDM untuk pelbagai jenis bahan. Sifat bahan, kadar suapan, kapasitansi dan jurang voltan adalah dipilih sebagai parameter input yang direka bentuk dalam tiga peringkat berdasarkan eksperimen berfaktorial penuh. Model CANFIS ini berjaya meramal dengan tepat prestasi μ EDM yang terdiri daripada kadar penyingkiran bahan (MRR), jumlah pulsa nyahcas, lebihan potongan dan ketirusan hanya dengan satu model. Peratusan ralat min mutlak (MAPE) daripada ramalan model untuk data ujian bagi pelbagai prestasi seperti MRR, jumlah pulsa nyahcas, lebihan potongan dan ketirusan masing-masing mencatatkan 9.5% (90.5% ketepatan), 8.9% (91.1% ketepatan), 16.9% (83.1% ketepatan) and 15.7% (84.3% ketepatan). Penyelidikan ini mencadangkan pendekatan baharu dalam memodel dan meramal prestasi μ EDM dengan mengambil kira sifat bahan menggunakan kecerdasan buatan.

APPROVAL PAGE

I certify that I have supervised and read this study and that in my opinion, it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a thesis for the degree of Master of Science in Engineering.



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DECLARATION

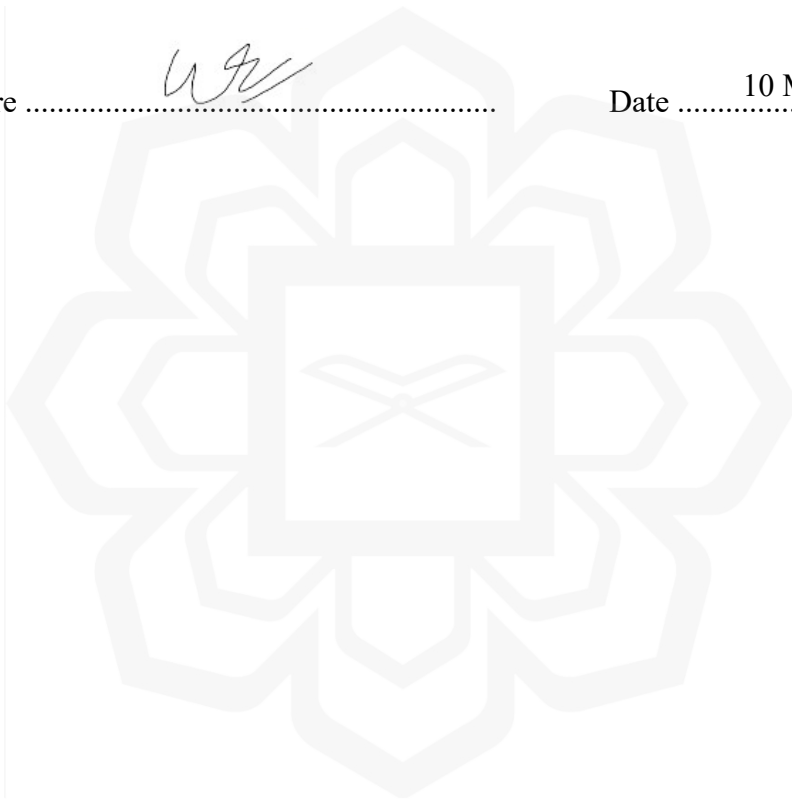
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TABLE OF CONTENTS

Abstract	ii
Abstract in Arabic	iii
Abstract in Bahasa Malaysia.....	iv
Approval Page.....	v
Declaration	vi
Copyright	vii
Acknowledgements	viii
Table of Contents	ix
List of Tables	xi
List of Figures	xii
List of Symbols	xiv
List of Abbreviations	xvii
CHAPTER ONE: INTRODUCTION	1
1.1 Research Background	1
1.2 Problem Statement.....	2
1.3 Research Objectives.....	2
1.4 Research Methodology	3
1.5 Research Scopes	4
1.6 Research Significance.....	4
1.7 Thesis Organization.....	4
CHAPTER TWO: LITERATURE REVIEW.....	6
2.1 Overview.....	6
2.2 EDM Working Principles	7
2.3 Micro-EDM	9
2.3.1 Power Supply Unit.....	10
2.3.2 Electrical Parameters.....	13
2.3.2.1 Gap Voltage.....	13
2.3.2.2 Peak Current	13
2.3.2.3 Pulse On Time	13
2.3.2.4 Pulse Off Time.....	14
2.3.2.5 Pulse Frequency.....	15
2.3.2.6 Electrode Polarity	15
2.3.3 Non-Electrical Parameters	15
2.3.3.1 Tool Material	15
2.3.3.2 Dielectric Fluid	16
2.3.3.3 Flushing	16
2.3.3.4 Discharge Gap	16
2.4 Performance in μ EDM.....	17
2.4.1 Efficiency	17
2.4.1.1 Material Removal Rate (MRR)	17
2.4.1.2 Tool Wear Ratio (TWR).....	18
2.4.2 Quality.....	18
2.4.2.1 Surface Roughness	18

2.4.2.2 Overcut	19
2.4.2.3 Taper	19
2.5 Modelling and Prediction in μ EDM	20
2.6 Chapter Summary	29
CHAPTER THREE: METHODOLOGY.....	30
3.1 Overview.....	30
3.2 Experimental Setup.....	30
3.3 Characterization.....	38
3.4 Modelling Approach.....	41
3.5 Chapter Summary	47
CHAPTER FOUR: RESULT AND DISCUSSION	48
4.1 Overview.....	48
4.2 Model Architecture.....	49
4.2.1 Fuzzy Rule	50
4.2.2 First Iteration.....	51
4.2.3 Final Iteration.....	58
4.3 Model Accuracy.....	60
4.4 Parametric Studies	64
4.4.1 Effect of Machining Ease Index and Feedrate on the μ EDM Performances	65
4.4.1.1 Study of MRR.....	65
4.4.1.2 Study of Average Discharge Energy	67
4.4.1.3 Study of Overcut.....	69
4.4.1.4 Study of Taper Angle	70
4.4.2 Effect of Capacitance and Gap Voltage on the μ EDM Performances	71
4.5 Chapter Summary	74
CHAPTER FIVE: CONCLUSION	75
5.1 Conclusion	75
5.2 Recommendation	76
REFERENCES.....	77
APPENDIX A: μEDM MACHINING RESULTS	83
APPENDIX B: μEDM MACHINING HOLES.....	87
APPENDIX C: REVIEW OF FUZZY INFERENCE SYSTEM.....	99
APPENDIX D: REVIEW OF ADAPTIVE-NETWORK-BASED FUZZY INFERENCE SYSTEM (ANFIS).....	103
APPENDIX E: REVIEW OF CO-ACTIVE NEURO-FUZZY INFERENCE SYSTEM (CANFIS)	106

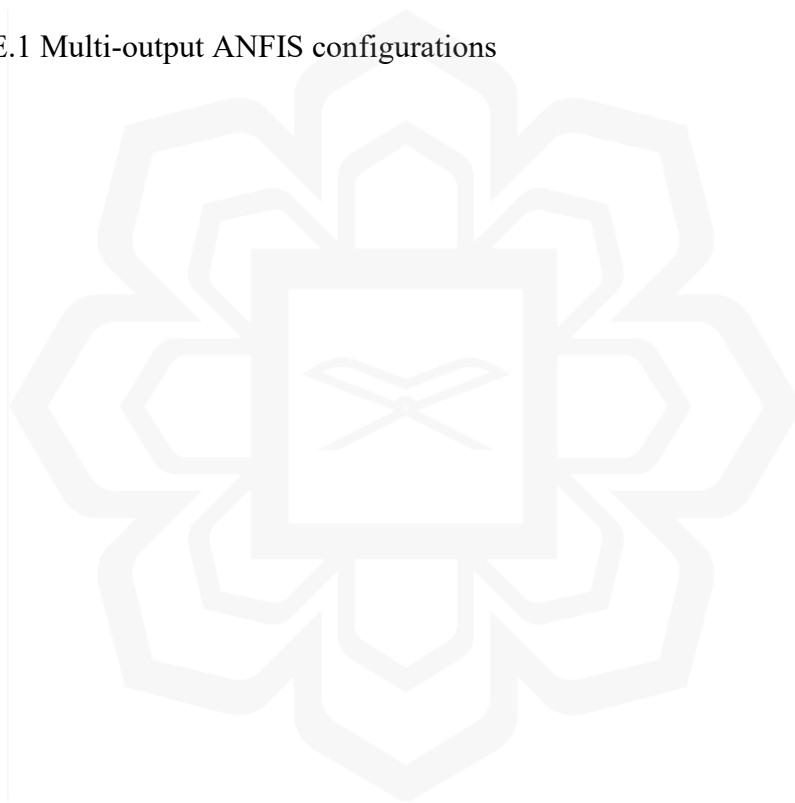
LIST OF TABLES

Table 2.1 Major differences between the conventional EDM and μ EDM	9
Table 2.2 Summary from the literature review	27
Table 3.1 Machining parameters for μ EDM machining	38
Table 3.2 CANFIS modelling parameters	43
Table 4.1 Interpretation of typical MAPE values	49
Table 4.2 Initial premise parameters	51
Table 4.3 Layer 2 output	51
Table 4.4 Layer 3 output	52
Table 4.5 Instantaneous error in layer 5	53
Table 4.6 Premise parameter first iteration result	55
Table 4.7 Consequent parameter first iteration result	56
Table 4.8 Consequent parameter final iteration result	59
Table 4.9 Correlation coefficient between various μ EDM inputs and outputs	63
Table A.1 μ EDM machining result	83

LIST OF FIGURES

Figure 1.1 Research methodology flowchart	3
Figure 2.1 EDM Schematic diagram	7
Figure 2.2 EDM process illustrations	8
Figure 2.3 The EDM phases	8
Figure 2.4 Pulse Generator used in EDM	11
Figure 2.5 Actual profile of single EDM pulse	14
Figure 2.6 Spark gap measurement	19
Figure 2.7 Taper angle (θ) measurement	20
Figure 3.1 Block diagram of the overall experimental setup	31
Figure 3.2 μ EDM Machine	31
Figure 3.3 Illustration of μ EDM setup for the experimental work	32
Figure 3.4 RC-circuit from the μ EDM power supply	33
Figure 3.5 μ EDM gap voltage monitoring circuit	34
Figure 3.6 Tool retraction algorithm flowchart	35
Figure 3.7 Oscilloscope image of the gap voltage waveforms	36
Figure 3.8 Measurement of μ EDM holes from the SEM images	39
Figure 3.9 Measurement of various parameters	40
Figure 3.10 CANFIS network architecture for the μ EDM system	44
Figure 3.11 The Simulink block for CANFIS training	45
Figure 3.12 The Simulink block for CANFIS testing and predicting	46
Figure 4.1 Premise parameters final iteration result	58
Figure 4.2 Comparison of experimental data and CANFIS predictions	62
Figure 4.3 CANFIS prediction accuracy of μ EDM performances	63
Figure 4.4 Effect of machining ease index and feedrate on the MRR	66

Figure 4.5 Effect of machining ease index and feedrate on the average discharge frequency	68
Figure 4.6 Effect of feedrate on the overcut for various discharge energy	69
Figure 4.7 Effect of machining ease index and feedrate on the taper angle	70
Figure 4.8 Effect of feedrate on taper angle for variation of discharge energy on aluminium	71
Figure 4.9 Effect of discharge energy on μ EDM performances	73
Figure C.1 Example of Linguistic variable	100
Figure D.1 Gaussian membership function	103
Figure E.1 Multi-output ANFIS configurations	106



LIST OF SYMBOLS

τ	Time constant (s)
R	Resistance (Ω)
C	Capacitance (F)
V_{cc}	DC supply (V)
E	Discharge energy per pulse (J)
V	Gap voltage (V)
T_{on}	Pulse on-time (s)
T_{off}	Pulse off-time (s)
f	Pulse frequency (Hz)
V_w	Volume of material removed from workpiece (m^3)
T_m	Machining time (s)
h	Thickness of workpiece (m)
π	Pi
d	Top surface hole diameter (m)
b	Bottom surface hole diameter (m)
V_e	Volume of material remove from electrode (mm^3)
D_f	Hole entrance diameter (m)
D_{Tool}	Electrode's diameter (m)
D_{top}	Top surface hole diameter (m)
D_{Bottom}	Bottom surface hole diameter (m)
R^2	Goodness-of-fit measure
x	Variable name

$T(x)$	Term-set of x
U	Universe of discourse
G	Syntactic rule
M	Semantic rule
X	Universe of discourse
μ_{NL}	Membership values for negative large
μ_{NS}	Membership values for negative small
μ_{DP}	Membership values for desired position
μ_{PS}	Membership values for positive small
μ_{PL}	Membership values for positive large
AND	Conjunction
OR	Disjunction
max	Maximum
\cup	Union operator
\cap	Intersection operator
$prod$	Product
Min	Minimum
$probor$	Probabilistic OR
N_{Rules}	Number of rules
N_{Input_terms}	Number of input terms
i	Number of input variable
j	Linguistic terms
x_i	Crisp input
k	k -th number of nodes

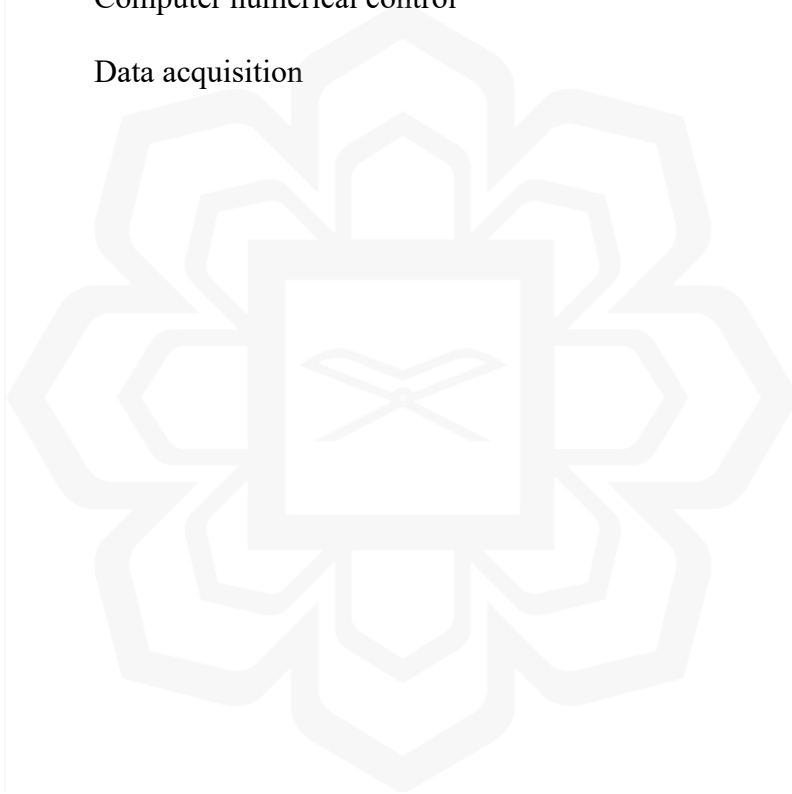
m	m -th number of networks
\overline{W}_k	Normalized activation value of the k -th node
f_k	Consequence parameters
λ	Thermal conductivity (W/mK)
θ	Melting point (K)
ρ	Electrical resistivity (Ωcm)
E_d	Discharge energy per pulse (J)



LIST OF ABBREVIATIONS

FET	Field effect transistor
MRR	Material removal rate
PWM	Pulse width modulation
RC	Resistance-capacitance
MOSFET	Metal oxide semiconductor field effect transistor
EDM	Electrical discharge machining
TWR	Tool wear rate
DOC	Diametrical overcut
ANN	Artificial neural network
FIS	Fuzzy inference system
ANFIS	Adaptive neural fuzzy inference system
MODE	Multi-objective differential evolution
MOABC	Multi-objective optimization using an artificial bee colony algorithm
GA	Genetic algorithm
FEM	Finite element method
PSO	Particle swarm optimization
NN	Neural network
MTI	Material technology index
CANFIS	Co-active neural fuzzy inference system
MANFIS	Multi adaptive neural fuzzy inference system
Ti	Titanium
NL	Negative large

NS	Negative small
DP	Desired position
PS	Positive small
PL	Positive large
COG	Centre of gravity
WA	Weight average
LSE	Least square estimate
CNC	Computer numerical control
DAQ	Data acquisition



CHAPTER ONE

INTRODUCTION

1.1 RESEARCH BACKGROUND

Micro-manufacturing is a highly sought-after manufacturing process in the modern era. It enables the fabrication of microparts and components for various industries, including semiconductors, biomedical devices, automotive, and aerospace. Micro Electrical Discharge Machining (μ EDM) is a micromachining process that uses an electrical spark to erode conductive material. The non-contact interaction between the electrode and the workpiece makes μ EDM an effective method for machining metals regardless of their hardness. Hence, this eliminates mechanical stresses during the machining process.

Micro components and parts fabrication is a difficult task in the manufacturing process. For example, micro-hole machining requires a micron level setup. μ EDM is a miniature version of EDM specifically designed for microfabrication. A low discharge energy per pulse is critical for micro-level machining, which is accomplished by controlling parameters such as gap voltage, feedrate, and power supply type.

Over the recent years, modelling and prediction of the μ EDM machining process using soft computing and artificial intelligence have emerged. From the literature review, the different combinations of process parameters and performances, modelling techniques and workpiece –tool selection can lead to extensive research opportunities in modelling. So far, the implementation of artificial intelligence in predicting μ EDM performances based on material properties is still not established. Therefore, proper modelling for μ EDM performances on the different types of the workpiece material is needed for the μ EDM application. Since EDM is a non-linear and stochastic process,

coactive neuro-fuzzy inference system (CANFIS) is proposed to model and predict the μ EDM performances.

1.2 PROBLEM STATEMENT

The implementation of artificial intelligence in predicting μ EDM performances based on material properties is still not established. Moreover, the selection of μ EDM parameters remains a challenge since it is frequently based on machinist intuition and heuristic approaches.

1.3 RESEARCH OBJECTIVES

The study aimed to achieve the following objectives:

- 1- To design and perform μ EDM experiments by considering the material properties.
- 2- To implement and evaluate CANFIS model that incorporates material properties for μ EDM application.
- 3- To evaluate the relationships between the process parameters and the μ EDM performances.

1.4 RESEARCH METHODOLOGY

Flowcharts in Figure 1.1 summarized the research methodology.

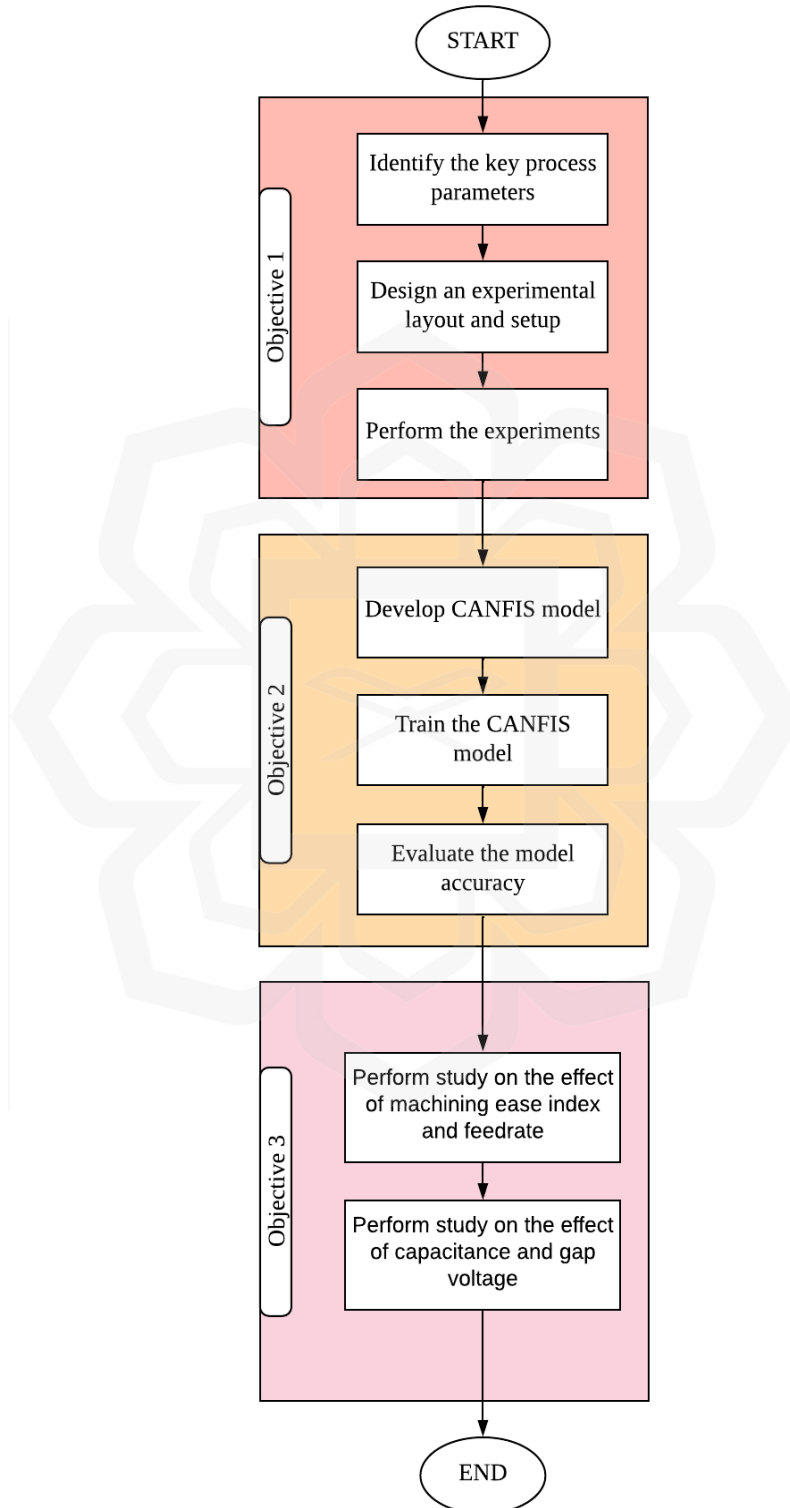


Figure 1.1 Research methodology flowchart

1.5 RESEARCH SCOPES

The research focuses on modelling and predicting μ EDM performances for the different workpiece materials according to the ease of machining order through soft computing-based model. Hence, this research only focuses on micro-scale, die sinking EDM. The workpiece materials used were aluminium, copper, and stainless steel. The μ EDM machine used for the experiment is an in-house-built μ EDM machine. It is powered by an RC-based power supply. It was configured with a $1k\Omega$ resistor with three parallel capacitors of $1nF$, $10nF$ and $100nF$. The gap voltage can be set from $50V$ to $100V$.

1.6 RESEARCH SIGNIFICANCE

This research proposes a novel approach in modelling and predicting μ EDM performances by considering workpiece's materials using artificial intelligence.

1.7 THESIS ORGANIZATION

This report is divided into five chapters, which are introduction, literature review, methodology, result and discussion and conclusion.

Chapter 1 introduces the fundamentals related to μ EDM. The motivation of this research is also explained in this chapter.

Chapter 2 conducts a review of the literature on EDM principles and previous research on modelling and predicting EDM performance. This chapter discusses the prior literature and the research gap.

Chapter 3 describes the research flow and methodology. Additionally, modelling techniques such as fuzzy logic, ANFIS, and CANFIS architectures are discussed. The design of the experiment, as well as the experimental setup, are defined in this chapter.

This chapter also explains the training procedure and parameter selections for CANFIS modelling.

Chapter 4 summarises the experimental data gathered in Chapter 3. This chapter discusses the model's training result and accuracy in detail. Additionally, relationships between process parameters and μ EDM performance were investigated.

Chapter 5 summarizes the research findings and presents the thesis's recommendation.



CHAPTER TWO

LITERATURE REVIEW

2.1 OVERVIEW

Machining processes are divided into two classes by M. P. Groover (1996). To begin, traditional machining operations such as turning, drilling, and milling use sharp cutting tools to remove a chip from the workpiece. Non-traditional machining, on the other hand, refers to a range of operations that remove material using different mechanisms. Mechanical, thermal, electrical, chemical, or mixtures of these techniques are used by this group. These non-traditional methods are required to machine new materials with unique qualities, as well as to produce odd and complex part geometries and avoid surface damage caused by conventional machining. The examples of non-traditional methods are the Ultrasonic Machining (UM) and Electrochemical Machining (EM).

Joseph Priestly discovered the erosive impact of electrical discharges in the 1770s, which started the history of EDM (Ho & Newman, 2003; Kumar, Singh, Singh, & Sethi, 2009). During World War II, two scientists, Lazarenko and Lazarenko started working on electrical discharge machining at Moscow University, and later in 1950, the Lazarenkos introduced an EDM system that used a resistance-capacitance power source (Ho & Newman, 2003; Kumar et al., 2009; Pandey & Singh, 2010). With the implementation of Computer Numerical Control (CNC) in EDM in the 1980s, the efficiency of the machining operation improved (Ho & Newman, 2003; Kumar et al., 2009) Figure 2.1 illustrates the schematic diagram of EDM.