DESIGN OF A FUZZY LOGIC INTELLIGENT FLUX SPRAYING SYSTEM FOR PCB PRODUCTION

This report is submitted per the requirement of the University Teknikal Malaysia Melaka (UTeM) for a Bachelor's Degree in Manufacturing Engineering (Hons.)

by

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FACULTY OF INDUSTRIAL AND MANUFACTURING TECHNOLOGY AND ENGINEERING

2024

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

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Sesi Pengajian: **2023/2024 Semester 2**

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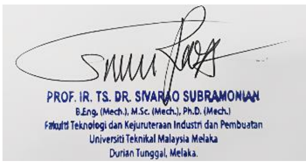

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APPROVAL

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ABSTRAK

Rancangan penyelidikan ini bertujuan secara drastiknya mengurangkan kejadian penolakan dan kadar pemprosesan semula PCB di syarikat-syarikat pengeluaran elektronik. Pada masa ini, sistem penyemburan flux yang digunakan oleh syarikat ini mempunyai kelemahan yang signifikan, terutamanya semasa syif malam, di mana terdapat kecenderungan tinggi bagi sistem untuk terlepas bekalan flux dan gagal mengesan kegagalan tersebut, yang membawa kepada kadar penolakan yang tinggi. Penyelesaian yang diusulkan memberi tumpuan kepada pembangunan dan integrasi sistem kawalan logik Fuzzy untuk penyemburan flux yang optimal. Beberapa kajian telah menyatakan kelebihan sistem logik Fuzzy dalam aplikasi kawalan ketepatan, terutamanya dalam mengekalkan keadaan yang optimum dalam proses yang kompleks. Matlamat utama penyelidikan ini ialah untuk memahami keterbatasan proses semasa, dan merancang dan melaksanakan sistem kawalan berasaskan logik Fuzzy yang menggabungkan sel beban, kawalan maklum balas, dan pemantauan kadar flux. Kajian ini membandingkan prestasi sistem baru dengan yang tradisional untuk menilai kecekapan dan pengurangan kadar penolakan. Metodologi penyelidikan melibatkan analisis yang terperinci sistem yang sedia ada, reka bentuk sistem kawalan baru menggunakan perisian CAD, dan simulasi prestasinya menggunakan MATLAB / Simulink. Sistem yang direka akan menjalani pelbagai ujian untuk mengesahkan keberkesanan. Ini akan membawa kepada pengurangan yang ketara dalam kadar penolakan PCB dan pemprosesan semula, dengan itu meningkatkan kecekapan pengeluaran, mengurangkan sisa, dan menjimatkan kos untuk syarikat. Selain itu, hasilnya akan menyumbang kepada badan pengetahuan dalam kawalan penyemburan flux dalam pengeluaran PCB.

ABSTRACT

This research proposal aims to drastically reduce the incidence of through-hole Printed Circuit Board (PCB) rejection and rework rates in Electronics manufacturing companies. Currently, the flux spraying system employed by the company presents significant shortcomings, especially during the night shift, where there is a high propensity for the system to miss flux supply and fail to detect such malfunctions, leading to high rejection rates. The proposed solution pivots on the development and integration of a fool-proof fuzzy logic control system for optimal flux spraying. Several studies have lauded the advantages of fuzzy logic systems in precision control applications, notably in maintaining optimal conditions in complex processes. The key goals of this research are to understand the limitations of the current process, and design and implement a fuzzy logic-based control system incorporating load cells, feedback control, and flow rate monitoring. The study compare the performance of the new system with the traditional one to evaluate the efficiency and reduction in rejection rates. The research methodology involves rigorous analysis of the existing system, designing the new control system using CAD software, and simulating its performance using MATLAB/Simulink. The designed system would be prototyped and subjected to an array of tests to verify its effectiveness. This lead to a significant reduction in the rate of PCB rejections and reworks, thereby increasing production efficiency, reducing waste, and saving costs for the company. Additionally, the results will contribute to the body of knowledge in flux spraying control in PCB manufacturing.

DEDICATION

I would be honored to express my deepest gratitude to my loving family, who have played a vital role in shaping my personal and professional development journey. Their everlasting love, knowledge, and unbreakable belief in my potential have created in me an insatiable thirst for education and a burning desire to succeed. They made incalculable sacrifices to guarantee that I had access to the best educational possibilities from the start of my life, establishing the groundwork for my intellectual development and paving the road for a prosperous future. Furthermore, I give my deepest gratitude and admiration to my treasured circle of close friends, whose unwavering support has been a constant source of inspiration and strength throughout the grueling years of my academic achievements. Their constant presence, support, and faith in my skills have served as guiding signs, illuminating my way and empowering me to overcome obstacles with dedication and determination

ACKNOWLEDGMENTS

I would like to express my gratitude for all my efforts to my Bachelor's Degree Project Supervisor, Prof. Ir. Ts. Dr. Sivarao a/l Subramonian for all the advice and guidance throughout the process of completing this dissertation, especially in guiding me in report drafting and guidance throughout the report content.

Not to forget the project coordinator, Dr. Chang Siang Yee, for continuously keeping me updated on the project submission timetable and teaching all degree students how to write a PSM dissertation report. I would like to express my gratitude to all of my lecturers, siblings, and friends who have never stopped encouraging and motivating me during my path. At the end of my dedication phrases, I complete this dissertation on behalf of all those who have helped by mentioning the accomplishments that belong to all of us.

Last but not least, I'd like to express my deepest appreciation to everyone who helped finish this report. Without the above-mentioned help and motivation, this report may be difficult to complete.

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PCB	-	Printed Circuit Board
FIS	-	Fuzzy Inference System
VOC	-	Volatile Organic Compound
AI	-	Artificial Intelligence
DGA	-	Dissolved Gas Analysis
ECG	-	Electrocardiogram
ToF	-	Time of Flight

CHAPTER 1 :
INTRODUCTION

1.1 Research Background

In manufacturing electronics products, PCBs are one of the main components required to be produced and assembled. Most electronic components will be placed on PCBs and highly likely will be soldered to them. To help the soldering process, it is required to have another significant process called flux spraying. The PCB (Printed Circuit Board) assembly process involves applying flux. Flux spraying machines are a significant development in the electronics manufacturing industry. Emerged in the late 1980s, flux spraying revolutionized the application of no-clean fluxes as alternatives to Freon for cleaning flux residues from PCBs. Traditional foam or wave techniques proved inadequate for these new fluxes, leading to issues such as lack of process control, solvent evaporation, non-uniform flux deposition, and frequent need for titration. Flux spraying addressed these challenges by offering better control and uniformity (Bixenman & Tolla, 2019.). Figure 1.1 shows the wave soldering process.

Wave soldering was a process used in electronics manufacturing to solder components onto printed circuit boards (PCBs). It involved passing the PCB, which had components placed on it, over a wave of molten solder. The board was first coated with flux to clean the surfaces and enhance solder flow. Then, it was preheated to prevent thermal shock. As the board moved over the solder wave, the solder adhered to the exposed metal areas, creating reliable electrical connections. This method was efficient for soldering multiple components simultaneously and was commonly used for through-hole technology, although it could also be adapted for some surface mount devices.

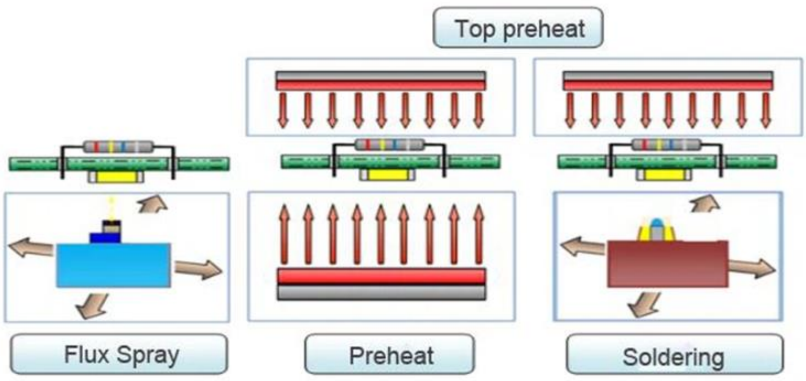


Figure 1.1: Wave Soldering Process

However, no-clean fluxes introduced their own set of process challenges. Stringent process control became crucial with generally lower percentages of active materials than traditional fluxes. Key parameters in flux spraying include uniformity and repeatability of deposition, the amount of flux deposited per unit area, preheat temperature and profile, the ability of the flux to penetrate through-hole barrels to the topside, and solder pot temperature. Deviations in any of these parameters can lead to suboptimal results.

Manufacturers of flux spraying equipment must ensure compatibility with various types of fluxes and provide uniform, repeatable deposition across a range of flow rates. The equipment should also deliver a spray with sufficient velocity to achieve good topside fills, a challenging task with VOC-free fluxes on bare copper boards. Moreover, the ideal flux sprayer should be reliable and easy to maintain. Quality standards have become more stringent over time. While 25 percent variations in deposition uniformity were once acceptable, today's users expect less than 10 percent. Repeatability, or the variation in deposition from one PCB to another, is typically around 1 percent. Other operating conditions are also important for achieving good topside fills. For instance, synchronizing flux spraying with conveyor movement is crucial (Wojdat et al., 2019). Figure 1.2 shown an example of a flux spraying machine.

Figure 1.2: Flux Spraying Machine

Both reciprocating and non-reciprocating types of flux sprayers can yield acceptable results. However, reciprocating types are prone to mechanical failure due to their moving mechanisms and may have inherent flaws in deposition uniformity due to overlap between successive passes. Some manufacturers have addressed this by modifying the spray direction to align with the PCB's path.

One of the biggest advantages of flux spraying is that it provides a much more uniform and repeatable deposition of flux. This is because the flux is sprayed onto the circuit board in a controlled manner, rather than being applied in a large wave or foam. This improved process control can help to reduce the number of defects in solder joints and improve the overall quality of the manufactured product (Berger, 2003).

Another major advantage of flux spraying is that it can significantly reduce solvent evaporation. This is because flux spraying machines typically use less solvent than other fluxing methods. This can help to reduce VOC (Volatile Organic Compound) emissions and improve workplace safety. In addition, flux spraying can help to reduce flux consumption by up to 93% compared to other methods. This can save manufacturers a significant amount of money over time (Shea Thomas Chinnici, 2013).

Flux spraying machines also require less maintenance than other fluxing methods, which can help to reduce downtime and improve productivity. Flux spraying can also help to improve solder wetting, which can lead to stronger and more reliable solder joints. Additionally, flux spraying can help to achieve better topside fillets, especially on bare copper boards. This is important for ensuring good electrical connectivity and preventing solder bridging.

Overall, flux spraying offers several significant benefits for electronics manufacturers. It can help to improve process control, reduce costs, and improve the quality of solder joints. Flux spraying machines are an essential tool for electronics manufacturers who want to improve the quality and reliability of their products.

Some specific examples of how flux spraying can be used to improve the electronics manufacturing process are flux spraying can be applied to complex circuit boards with many components. This can be difficult to do using traditional fluxing methods, such as foam and wave fluxing. Still, flux spraying machines can easily apply flux to even the most complex circuit boards with precision and accuracy.

Next, flux spraying can be used to apply flux to circuit boards with different types of finishes. This can include bare copper boards, circuit boards with a conformal coating, and circuit boards with a solder mask. Also, Flux spraying machines can be adjusted to apply the correct amount of flux to each type of finish, ensuring that the flux is applied evenly and consistently. Plus, Flux spraying can be used to apply different types of flux, including water-soluble, no-clean, and VOC-free fluxes. This gives manufacturers the flexibility to choose the best type of flux for their specific application. Flux spraying can be used to automate the fluxing process. This can help to improve efficiency and reduce the risk of human error.

Flux spraying systems use various controller systems to ensure precise and efficient operation. Cheer Sonic's UAM6000 Dual Flux Spraying System uses a dual channel and user-friendly control system. The dual flux function allows for rapid process conversion, providing greater flexibility in wave soldering flux. This system provides precise metered flow with dual flux delivery.

Flux Spraying System and Method (Patent US20100252649A1), this patented system controls a flux sprayer to selectively spray soldering flux onto a printed circuit board (PCB) by a fixture. The control system comprises a statistic module, a calculation module, and a control module. The statistic module records attributes of the fixture to determine spraying areas on the fixture. The calculation module calculates the movement parameters of the flux sprayer, the movement length during a movement period, and the spraying segments of the flux sprayer. The control module directs the flux sprayer to coat the target areas of the PCB through the openings of the fixture.

These controller systems are designed to provide precise control over the flux spraying process, ensuring uniform coverage, and minimizing waste. However, the specific controller system used can vary depending on the specific requirements of the manufacturing process.

1.2 Problem Statement

The primary obstacle the electronics manufacturing sector faces is the limits of current flux spraying systems, particularly the lack of a reliable monitoring system for identifying lost flux supply. Present methods are not able to quickly detect situations in which the flux supply is neglected, particularly at night. This crucial shortcoming causes through-hole printed circuit board (PCB) rejection rates to rise, which has a substantial effect on production costs and the manufacturing process's overall effectiveness.

The fact that the existing systems do not have a real-time monitoring mechanism to guarantee the precise and continuous transmission of flux makes them inadequate. This shortcoming impedes not only the accuracy of flux application but also sets off a series of problems, such as uneven flux dispersion and an overabundance of flux residue. These shortcomings therefore lead to field dependability issues and the possibility of delamination and voids in the underfill. Moreover, the current procedures which frequently make use of pressure spray techniques prove to be cumbersome, sluggish, and unfit for the needs of large-scale manufacturing.

As a result, to identify and address instances of missing flux delivery, a sophisticated flux spraying system with a thorough monitoring mechanism is desperately needed. Closing this crucial technological gap would reduce rejection rates, increase production effectiveness, and eventually improve the manufacturing process's overall quality.

1.3 Objectives

a) To analyse the current process of flux spraying in through-hole PCB production.

b) To design a fuzzy logic control system to monitor the fluid supply system.

c) To validate a newly designed fuzzy logic system through MATLAB Simulation.

1.4 Research Scope

The scopes of research are as follows:

a) Research on the effects of flux spraying parameters on the quality and reliability of through-hole PCB assembly. This research will focus on understanding how variations in flux spraying parameters influence mechanical and electrical properties, particularly aiming to optimize the process for strength and reliability.

b) Study the potential of using fuzzy logic control in the flux spraying process for better control of spray parameters, reduced material waste, and improved system maintenance. Emphasis will be placed on designing a fuzzy logic control system using MATLAB Fuzzy Logic Designer to ensure precise flux application and easy monitoring of fluid supply levels.

c) Design and simulate different fuzzy logic control strategies for flux spraying using MATLAB/Simulink. Through comprehensive testing, the research will identify the most effective control strategy, evaluating the performance in terms of spray accuracy, reduction in PCB defects, and overall process efficiency. The anticipated outcomes include a more reliable flux spraying system, fewer rejections, enhanced efficiency, and significant cost savings.

CHAPTER 2 :
LITERATURE REVIEW

This chapter mainly describes the theory and research which have been defined and done by various researcher years ago. Related information of previous studies is extracted as references and discussion based on their research about fuzzy logic, applications in industries and structure.

2.1 Control System and Monitoring

2.1.1 Fuzzy Logic System Overview

Any system equipped with fuzzy logic reasoning is considered to be a fuzzy system. It can be a sub-module of a non-fuzzy system, or an entire system designed to perform fuzzy reasoning. The implementation strategy and nature of fuzzy logic allow for a fuzzy component to be isolated from the non-fuzzy (crisp) parts of the system. The connections between fuzzy and crisp components are practically realized through crisp-to-fuzzy and fuzzy-to-crisp converters, also known as Fuzzification and Defuzzification modules. These modules are integrated parts of any fuzzy system. The top-level block diagram of a generic fuzzy logic system is illustrated in Figure 2.1.

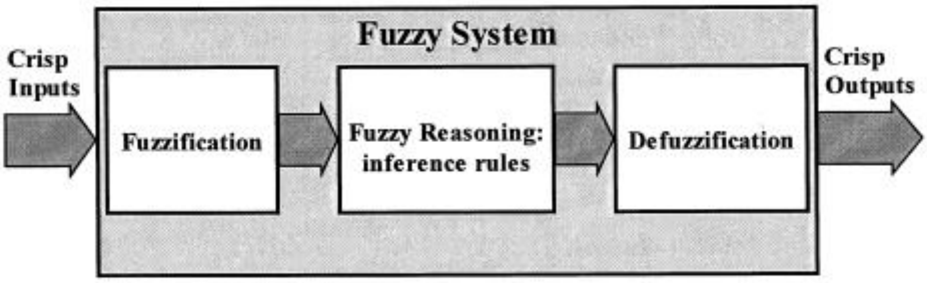


Figure 2.1: Fuzzy Block Diagram

Fuzzy logic systems can be designed to perform many different tasks and can be used in many applications. Broadly, fuzzy systems can be divided into four categories:

a) Prescriptive systems. These systems undertake specific decisions in response to changes in input signals. Control systems fall under this category.

b) Descriptive systems. These systems identify event problems or objects by classification characteristics. Detection, monitoring, pattern recognition, and diagnostic systems are classified as descriptive systems.

c) Optimization systems. These systems establish conditions and actions necessary to achieve some degree of efficiency or performance characteristics. The optimization is performed considering complexity, time, speed, or other controlled domains.

d) Predictive systems. These systems require predicting possible future outcomes of a process in the controlled domain.

Fuzzy logic systems have found their way into many industrial applications. They are currently used in the medical field, aviation, aerospace industry, robotics, seismology, heavy machinery, navigation, domestic electronics, shipbuilding, automobile industry, and even education. These systems are designed to perform many different tasks, including monitoring, identifying, controlling, tracking, diagnosing, predicting, and optimizing.

2.1.2 Monitoring System.

Monitoring systems are designed to monitor the environment for specific events and produce responses to the occurrence of these events. Monitoring systems with fuzzy logic reasoning have found large usage in many different fields. One of them is medical. In (Khalil et al., 2021), a fuzzy logic system for monitoring SIDS risk infants' life-threatening events is presented. In this system, fuzzy algorithms are used to monitor respiration, electrocardiogram (ECG), and blood oxygen saturation (SpO2), to make an intelligent assessment of potential life-threatening events. Each monitoring signal has a corresponding fuzzy logic identification module that includes membership functions and a rule matrix to produce an alarm when decided so by the defuzzification process with fuzzy Centroid.

The system can monitor simultaneously all input events. The fuzzy logic algorithm is implemented as a software program on a microcontroller and consists of multiple inference compositions and 6-rules-based fuzzy logic.

A system with a very similar 6-rules fuzzy logic concept is presented in (Khalil et al., 2021). This system monitors cardiovascular signals for cardiac problem detection. This fuzzy logic approach of this system is similar to (Alhumade et al., 2021) except that this system incorporates a unique fuzzy logic decision function that smoothes probability distribution for patient parameters.

A little different fuzzy logic approach is presented by (Wang & Li, 2021), where an online advisory system for monitoring and controlling the depth of inhaled anesthesia is described. This system monitors online measurements of pressure, heart rate, and other clinical information, and advises of the recommended dosage of anesthesia for the patient. The system combines feedback on patient reaction to the introduced level of anesthesia and a fuzzy reasoning controller producing a recommended dosage. The fuzzy logic controller has two multiple inputs corresponding to clinical data and a flexible fuzzy rules mechanism that allows modification of fuzzy rules depending on the level of monitoring.

Another system for monitoring morphological changes in the spinal cord for people with back injury is presented. A fuzzy logic tissue classification algorithm is used to segment array and white matter regions for morphometric analysis. The fuzzy logic system uses 2 inputs, 3 Gaussian membership functions with a 3x3 fuzzy rule matrix, and a fuzzy centroid-based defuzzification mechanism, to classify grey matter regions and intact white matter tracts. The fuzzy logic Toolbox in MATLAB is used for the implementation of the system.

Another important field, in which fuzzy logic monitoring has been applied, is seismic activity monitoring. A fuzzy logic system has been developed to monitor earthquake activity and to reduce the absolute motion of the structure base. The structure is controlled through a single force applied from a controllable MR damper placed on the first story of the structure. The restraining control force is computed in real time, using an evolutionary fuzzy logic controller. The functionality of the proposed system has been verified through extensive simulation of a six-story structure, using disparate earthquake ground motions.

Even in education, the monitoring students' actions system using teachers' expertise was developed and presented. This system uses fuzzy logic to produce subjective assessments based on teachers' experience. The system incorporates a networking model of fuzzy logic modules, where each input has its fuzzifier and each fuzzy module incorporates inputs from all fuzzifiers. The defuzzification stage is individual for each fuzzy module, thus producing multiple outputs. This system has a very large reasoning capability equipped with neural networks, however, the fuzzy rules matrixes are very large and require extensive computational power. That approach is suitable for offline computations or simulations.

2.2 Applications of Artificial Intelligent & Expert System

2.2.1 Introduction to Intelligent System

Artificial intelligence (AI) is a wide-ranging sector within the realm of information technology. It's commonly described as the replication of human-like intelligence in digital computers or robotic systems, as noted by B. J. Copeland, 2018. The roots of contemporary AI can be traced back to the 1950s, and it has evolved over the past few centuries in areas such as evolutionary and genetic programming, machine learning, and reinforcement learning (M. Flasinski, 2016). To fully grasp the concept of artificial intelligence, it's crucial to understand its fundamental principles and operational mechanisms.

Intelligent systems in the context of this work fall into autonomous. Autonomous systems unlike supervised ones can operate using their own experience without human (supervisor) intervention or help (S. Russell, 2003). The development of autonomous systems faces a wide range of problems concerning decision-making, knowledge acquisition, and representation because these systems have to acquire, and organize knowledge and make a decision on their own. Therefore there are necessarily situations in which a decision has to be made on incomplete knowledge and limited information about the system's environment.

As regards knowledge representation autonomous systems are specific because they link units of knowledge unaided and unassisted by humans (supervisors). So the development of autonomous systems is usually more complex than the development of supervised systems or systems with limited autonomy. The development becomes even more complex if the system is developed for operation in sophisticated environments that are highly dynamic, hardly predictable, and include a larger number of elements and links connecting them. It means that knowledge representation schema and decision-making process become more sophisticated from structural and control aspects.

2.2.2 Introduction and Evolution of Fuzzy Logic

Traditional logic operates on the binary principle of true or false, hot or cold, tall or short. This can fall short of representing the nuances of the real world, where many concepts exist on a spectrum. Fuzzy logic, pioneered by Dr. Lotfi Zadeh in 1965, addresses this limitation by introducing intermediate values between binary opposites. Zadeh's inspiration stemmed from earlier philosophical insights into uncertainty and degrees of truth. Aristotle, while establishing binary logic, acknowledged its limitations. Plato and others further questioned the rigidity of binary evaluations, contributing to the idea of multi-valued logic where "everything is a matter of degree." Fuzzy logic embraces this notion. It extends beyond the confines of true/false and incorporates degrees of truth such as "very hot," "moderately tall," or "somewhat fast." This enables a more accurate portrayal of real-world systems, acknowledging the inherent ambiguity and complexities that traditional logic struggles to capture(Wang & Li, 2021).

The mathematical formulation of fuzzy sets, introduced by Zadeh, allows everyday terms like "tall" or "hot" to be processed by computers. This facilitates decision-making processes akin to human reasoning, where imprecise and subjective concepts play a significant role. Fuzzy logic's impact extends beyond theoretical elegance. Its practical applications have led to innovative advancements in diverse fields. From Sony's handwriting recognition technology to Sugeno's helicopter flight control system, from Nissan's car engine control to Aptronix's industrial automation solutions, fuzzy logic has demonstrably improved product efficiency and performance. fuzzy logic emerges as a powerful tool for representing and navigating the inherent fuzziness of real-world systems.

2.2.3 Fuzzy Sets

In classical set theory, elements either belong or don't belong to a set, creating a stark binary distinction. Fuzzy sets, however, introduce the concept of partial membership, acknowledging that elements can belong to a set with varying degrees of truth. This nuance is captured by a membership function, which assigns a value between 0 (complete non-membership) and 1 (complete membership) to each element, as visually illustrated below. Fuzzy sets defy the rigid boundaries of classical sets. Instead, they embrace a gradual transition from membership to non-membership, reflecting the ambiguity inherent in many real-world phenomena(Rahmani et al., 2021). This flexibility allows for more accurate modeling of systems where classification isn't always clear-cut, such as determining whether a person is "tall" or a temperature is "warm."

Fuzzy sets often employ linguistic variables, which capture qualitative concepts using words rather than numbers. For example, variables like "tall" or "warm" can be quantified using membership functions that define the degree to which a given value aligns with the linguistic concept. This enables the integration of human-like linguistic reasoning into mathematical models.

The versatility of fuzzy sets has led to their widespread adoption across diverse fields, Fuzzy logic controllers excel in handling systems with uncertain or imprecise inputs, such as regulating temperature or balancing robotic movement. Fuzzy decision-support systems incorporate expert knowledge and subjective criteria to make informed choices in complex scenarios, such as medical diagnosis or financial investment. Fuzzy pattern recognition techniques effectively categorize data with overlapping features or ambiguous boundaries, finding applications in image processing, speech recognition, and more (Choy et al., 2021).

2.2.4 Application of Fuzzy

Fuzzy logic, a method of reasoning that resembles human reasoning, is applied to systems that require an imprecise mode of reasoning, offering solutions to complex problems in various fields. Its applications are diverse, including robotics, where it contributes to the development of more adaptive and responsive systems; washing machine control, where it enhances operational efficiency and effectiveness; nuclear reactor control, where it improves safety and stability; and information retrieval, where it refines search algorithms for more accurate results.

Fuzzy logic, once a theoretical curiosity, has blossomed into a versatile tool permeating an astonishing array of technical applications. Its ability to capture the inherent ambiguity and granularity of real-world systems makes it a potent force in optimizing performance and decision-making across diverse domains. Fuzzy algorithms deftly maintain spacecraft and satellite altitudes, navigating the intricate celestial dance of gravitational and atmospheric forces. Similarly, aircraft deicing vehicles leverage fuzzy rules to regulate fluid flow and mixture, ensuring efficient ice removal while minimizing waste and environmental impact.

Trainable fuzzy systems optimize idle speed control in vehicles, dynamically adjusting to engine temperature and load conditions for enhanced fuel efficiency and emissions reduction. Automatic transmissions benefit from fuzzy-driven gear shifting, considering engine RPM, vehicle speed, and throttle position for smoother and more responsive driving experiences. Fuzzy logic also empowers intelligent highway systems and traffic control by dynamically adjusting signal timings and lane utilization based on real-time traffic data, leading to reduced congestion and improved safety (Carter et al., 2021).

Decision-making support systems in large companies find strength in fuzzy logic, incorporating subjective criteria and expert knowledge into personnel evaluation, resource allocation, and project management. Underwater target recognition tasks utilize fuzzy algorithms to analyze complex sonar and radar data, distinguishing friend from foe and enhancing situational awareness for informed defense strategies. Fuzzy logic also supports multivariable control of anesthesia during medical procedures, ensuring patient safety and comfort throughout the surgical journey.

Automatic exposure in video cameras is guided by fuzzy algorithms, dynamically adjusting settings to deliver optimal image quality regardless of lighting conditions. Air conditioning and heating systems leverage fuzzy logic for climate control, balancing desired temperature, energy efficiency, and occupant comfort. Domestic appliances, from washing machines to microwave ovens, benefit from fuzzy-driven operation tailoring their performance to specific needs and usage patterns. Banknote transfer security relies on fuzzy logic's keen eye, verifying authenticity through an in-depth analysis of physical and security features. Fund managers utilize fuzzy models to navigate market trends, assess risk, and make informed investment decisions for optimal portfolio performance (Abdillah et al., 2022).

Process control in industries like cement kilns and heat exchangers benefits from fuzzy logic's ability to optimize complex operations. Wastewater treatment plants and water purification systems utilize fuzzy models for dynamic control and quality assurance, while quantitative pattern analysis finds application in industrial quality control for identifying defects and anomalies with greater accuracy. Cheese and milk production processes are optimized by fuzzy logic models, considering factors like cheese curd texture, milk composition, and fermentation conditions for improved product quality and yield.

Ship autopilots rely on fuzzy algorithms for enhanced stability and efficiency, navigating challenging maritime environments with precision and adaptability. Fuzzy models also optimize route planning for marine vessels, minimizing fuel consumption and travel time while accounting for weather conditions and navigational hazards. Autonomous underwater vehicles benefit from fuzzy logic guidance, enabling them to perform complex tasks in challenging underwater environments while adapting to unforeseen circumstances.

Medical diagnostic systems gain a sharper focus with the help of fuzzy logic, integrating diverse symptoms, patient history, and laboratory test results to improve diagnostic accuracy and identify early-stage diseases. Trading decision systems leverage fuzzy models for market trend analysis and investor sentiment to inform optimal trading decisions, minimizing risk and maximizing returns. Security appliances benefit from fuzzy logic algorithms to detect and prevent intrusions, enhancing the overall security posture of networks and systems.

Automated train systems utilize fuzzy logic for optimized acceleration, braking, and stopping, ensuring passenger comfort and safety. Train schedule control benefits from fuzzy models that dynamically adjust schedules based on real-time traffic conditions and passenger demand, improving efficiency and reducing delays in transportation networks. Speech and handwriting recognition systems, facial characteristic analysis, and command analysis all benefit from the power of fuzzy logic algorithms.

The application of fuzzy logic in the context (Husniah & Supriatna, 2021) is primarily focused on the development of a predictive digital model for diagnosing the technical condition of power transformers. This model utilizes fuzzy logic in conjunction with the dissolved gas analysis (DGA) method to predict potential faults within transformers. By interpreting key gas criteria and the Dornenburg ratio method, the model can effectively identify the type of defect and its cause, if present. The fuzzy logic approach allows for the handling of uncertain and imprecise data, which is common in transformer diagnostics. The model's verification on 110 kV and 220 kV transformers demonstrates its high efficiency in fault prediction, making it a valuable computational tool for the operational personnel of power enterprises to facilitate maintenance and ensure reliable power supply.

2.3 Hardware Integration

2.3.1 Level Indicator

A level indicator is a device used to measure the level of fluids in various industrial applications. These devices are used to determine the level of liquid in tanks, drums, and pressure vessels. Some level indicators use a combination of probe sensors or float switches to sense water levels. The use of a level indicator is to gauge and manage water levels in a water tank. The control panel can also be programmed to automatically turn on a water pump once levels get too low and refill the water back to the adequate level. A water level indicator sensor, also known as a probe sensor, tells the control panel that corrective action is needed.

The importance of level indicators is manifold. They are easy to install, require very little maintenance, and have a compact design. Automatic water level indicators ensure no overflows or running of dry pumps. They save money by using less water and electricity. They can help avoid seepage of walls and roofs due to tanks overflowing. Automatic save you can save manual labor time. They consume very little energy, perfect for continuous operation. In certain situations where the nature of the fluid is dangerous or the place in which the liquid is stored is of such a nature that it is manually impossible to find the level, then the level indicators are of utmost importance.

2.3.1.1 Mechanical type indicator

Gauge glass, also known as sight glass, is a transparent glass tube that is fixed parallel to the liquid container. This simple yet effective device allows for the continuous indication of the liquid level within a tank or vessel (Mauer, 2022). The main element of the gauge glass is the gauge body, which incorporates the liquid channel and the seating faces for the chambered seals and sight glasses (Mauer, 2022). It is applicable in both open and closed tank arrangements, making it versatile for various applications (Mauer & Moreau, 2022). However, the accuracy of this device depends upon the cleanliness of the fluid and the glass (Mauer, 2022). Figure 2.2 shows the diagram of a gauge glass.

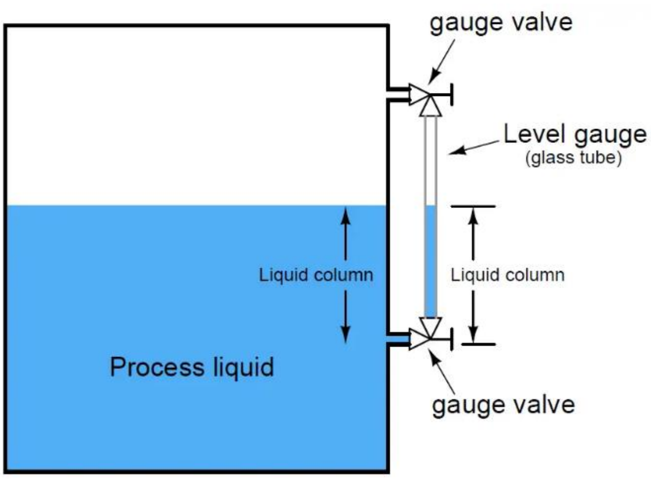


Figure 2.2: Glass Gauge

On the other hand, float-type indicators as shown in Figure 2.3 are designed to indicate the level in various tanks such as reservoirs and suction tanks. The model KF-100 is a float-type level indicator where a float with a built-in magnet, which is put on a stem, floats on the surface and goes up and down as the level varies (Muhammad Afiq, 2019). Reed Switches and Resistors being built in the stem can detect the resistance changes in the varying liquid levels (Muhammad Afiq, 2019). These indicators are reliable and versatile, with a scale and range that can be customized according to the specific needs of the customer (Muhammad Afiq, 2019). However, float and tape systems have a common problem with the tape hanging up, which often occurs if the long guide pipes are not perfectly vertical, where the tape rubs against the inside of the pipes.

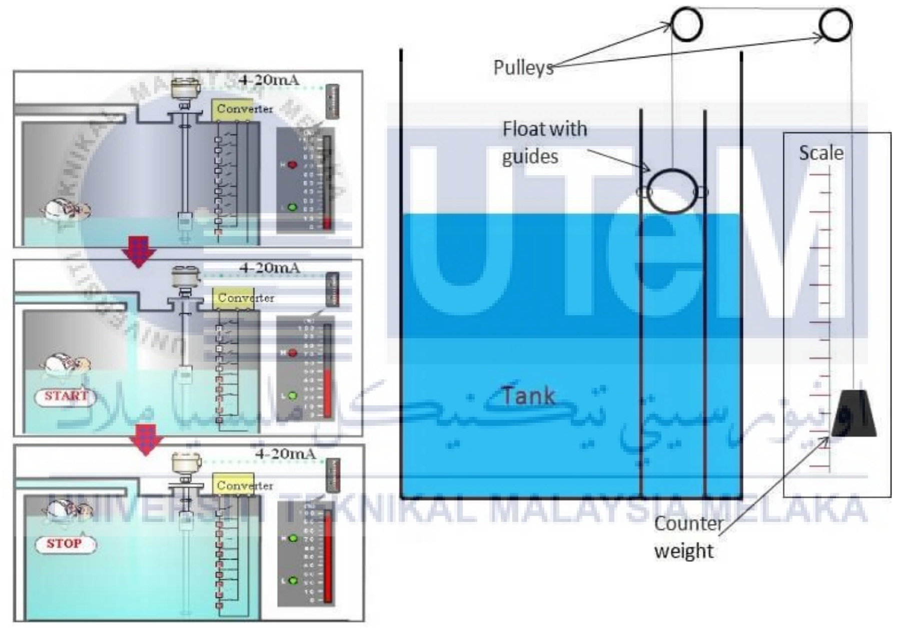


Figure 2.3: Float Type Indicator

2.3.1.2 Electrical type indicator

As shown in figure 2.4, capacitance level indicators are a critical component in fluid level-indicating systems. They operate on the principle of capacitance, which is the ability of a system to store an electric charge. This literature review aims to explore the principles, applications, and advancements of capacitance level indicators in fluid level indicating systems. Capacitance level measurement is based on the change in capacitance caused by the change in the level of the fluid. An insulated electrode and the tank wall act as the two plates of a capacitor, with the fluid acting as the dielectric.

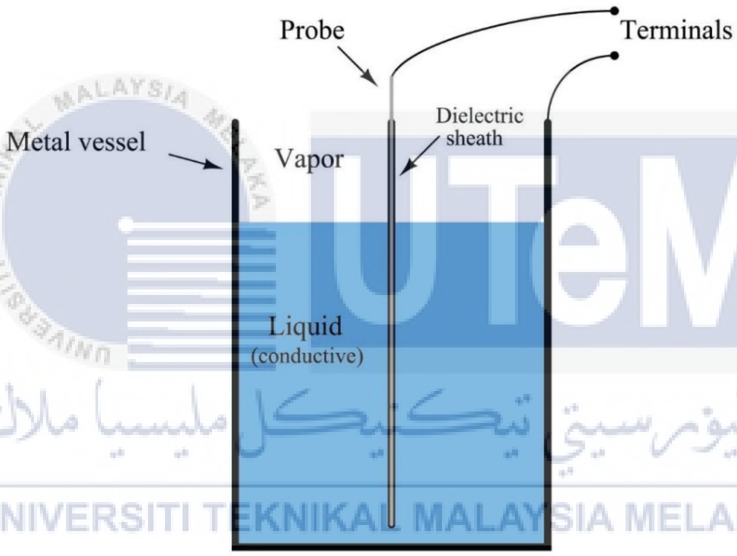


Figure 2.4: Capacitance Type Indicator

The capacitance depends on the fluid level, with an empty tank having a lower capacitance and a filled tank having a higher capacitance. Capacitance level indicators have found widespread use in various industries due to their versatility and reliability. They are used in the petroleum industry for oil level measurement, in the food and beverage industry for liquid level measurement, and in the chemical industry for the measurement of corrosive liquids(K. V. Santhosh, 2020). Recent advancements in capacitance level indicators have led to improved accuracy and reliability. Developments in microprocessor technology have enabled the creation of smart capacitance level indicators that can self-calibrate and compensate for changes in temperature and pressure (David Wang, 2015).

Infrared level indicators are not only reliable but also versatile, making them an ideal choice for a wide range of applications. In the petroleum industry, for instance, they are used to measure oil levels in tanks. The infrared light can penetrate the surface of the oil, providing an accurate measurement of the oil level. This is crucial for maintaining the efficiency of the oil extraction and refining process.

In the food and beverage industry, infrared level indicators, shown in Figure 2.5, play a vital role in ensuring the quality and safety of products. They are used to measure the level of liquids in tanks and containers, such as milk in a dairy plant or beer in a brewery. By providing accurate and real-time measurements, these devices help prevent overflows and underfills, reducing waste and improving productivity. In the chemical industry, infrared level indicators are used to measure the level of corrosive liquids. These devices are particularly useful in this context because they do not come into contact with the liquid, preventing damage to the sensor. Recent advancements in technology have led to significant improvements in the accuracy and reliability of infrared-level indicators. For instance, the development of smart infrared level indicators, which can self-calibrate and compensate for changes in temperature and pressure, has greatly enhanced their performance. These devices use advanced algorithms to analyze the reflected light, allowing them to provide more accurate measurements. Furthermore, the integration of infrared level indicators with wireless technology has opened up new possibilities for remote monitoring and control. This is particularly useful in large industrial plants, where tanks and containers may be located in hard-to-reach areas.

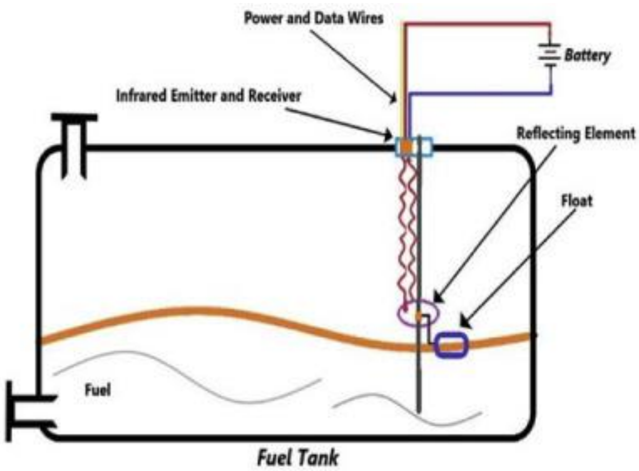


Figure 2.5: Infrared Level Indicator (O.Alonso et al,2020)

Ultrasonic sensors in fluid level monitoring operate by emitting high-frequency Fsound waves and measuring the time it takes for the echo to return. The time delay is then used to calculate the distance or level of the fluid. The sensor excites the transducer by hitting it with a series of pulses and with frequencies in the range of kHz to MHz. The difference in Ftime between the start and stop time-of-flight (TOF) indicates the fluid level. Ultrasonic sensors offer several advantages in fluid level monitoring (Fares Ng, 2020). They provide non-contact measurement, preventing contamination and damage. They are known for their high accuracy and repeatability, even in challenging conditions. Furthermore, they are easy to install and require minimal maintenance. They can monitor and detect nearly any liquid, making them versatile. Moreover, they are cost-effective, enabling the creation of systems that reliably determine wave height and water levels at much lower installation and maintenance costs. Ultrasonic sensors offer several advantages in fluid level monitoring. Figure 2.6 shows the simple notation of calculating distance using ultrasonic wave.

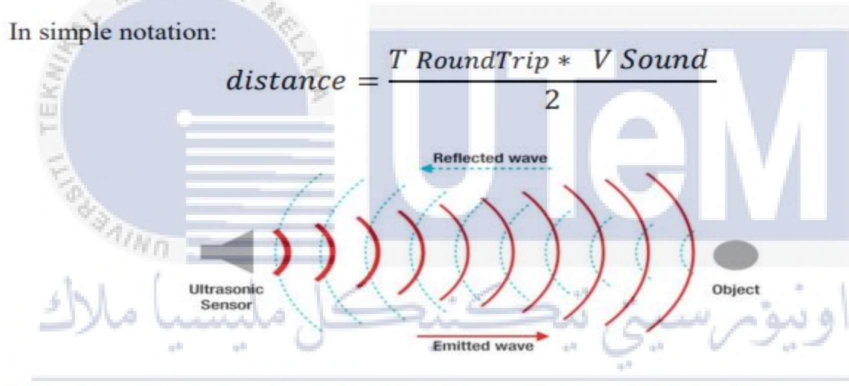


Figure 2.6: Distance Travel in Ultrasonic Wave

They provide non-contact measurement, preventing contamination and damage (Gao, 2021). They are known for their high accuracy and repeatability, even in challenging conditions. Furthermore, they are easy to install and require minimal maintenance. They can monitor and detect nearly any liquid, making them versatile. Moreover, they are cost-effective, enabling the creation of systems that reliably determine wave height and water levels at much lower installation and maintenance costs. Recent research has focused on improving the accuracy and reliability of ultrasonic sensors in fluid-level monitoring. For instance, a study evaluated the level of open channel flows using a combination of Arduino and ultrasonic sensors whilst considering turbulence. Another research enhanced the ultrasonic waveguide sensor’s fluid level sensitivity using through-transmission and pulse-echo techniques simultaneously. These studies highlight the ongoing efforts to optimize the performance of ultrasonic sensors in fluid level monitoring.

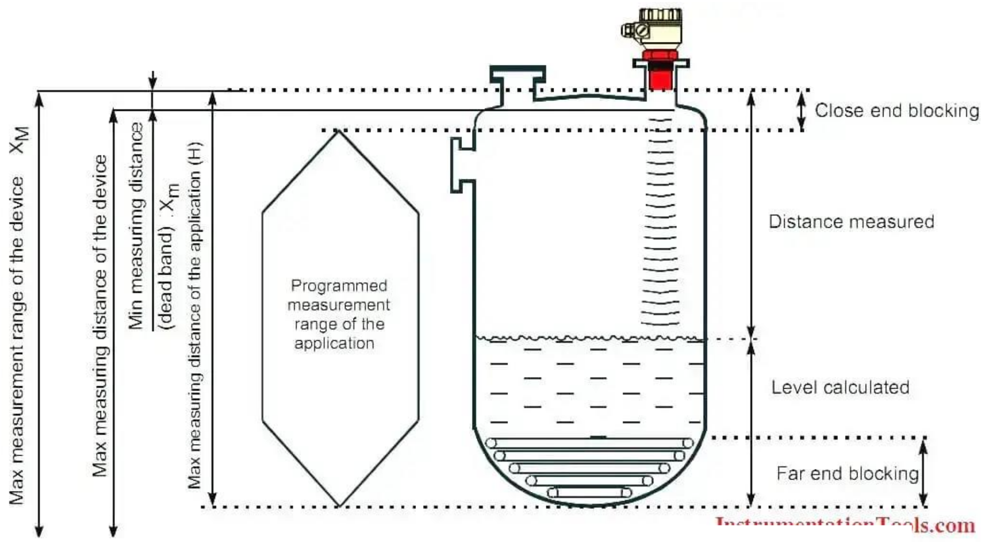


Figure 2.7: Ultrasonic Level Indicator

Fiber optic fluid level indicators, shown in Figure 2.8, are a type of sensor that operates on the principle of light transmission and reflection (Astapoz, 2021). In the absence of liquid, the transmitted light is directed back to the phototransistor through the optical head, outputting a 'low-level' signal. This principle allows for the detection of fluid levels in a variety of applications, from monitoring the level of flammable liquids in high-capacity tanks to tracking changes in petroleum products during pumping at oil storage depots (Astapoz, 2021).

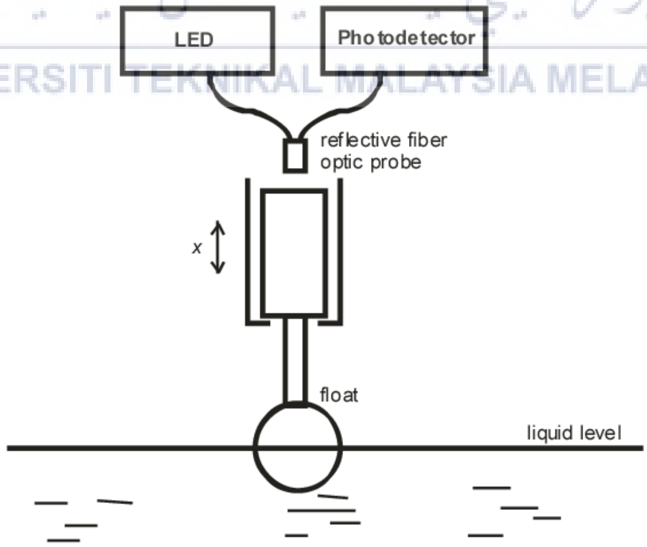


Figure 2.8: Fiber Optic Level Indicator (S. Sediva et al,2012)

One of the main advantages of fiber optic fluid level indicators is their immunity to electromagnetic interference. This makes them particularly useful in environments where other electronic devices are present. They are also compact, which allows for their use in applications where space is limited. Furthermore, these sensors are resistant to hostile environments, including those that may contain hazardous chemicals (Harsh Gupta, 2020). This resistance extends to their geometric versatility and ruggedness, which enables them to withstand a range of physical conditions. Another significant advantage is their ability to perform sensor multiplexing and distributed sensing over a single fiber. This means multiple sensors can be used simultaneously without interference, providing a comprehensive overview of fluid levels in a system.

However, fiber optic fluid level indicators also have some disadvantages. One of the main drawbacks is the fragility of optical fibers. They are more susceptible to damage compared to copper wires, which can limit their applicability in certain environments. Additionally, fiber-optic intensity-based sensors have limitations imposed by variable losses in the system that are unrelated to the environmental effect being measured. This can affect the accuracy of the sensor readings and may require additional calibration or adjustment (Astapoz, 2021).

Recent research in the field of fiber optic fluid level indicators has focused on the development of spark-explosion-safe devices with hydrostatic fiber-optic liquid level sensors and position-sensitive detectors. These devices are designed for continuous monitoring of liquid levels, measuring the displacement of the bottom of a bellows under the influence of the hydrostatic pressure created by a column of the liquid. They also feature automatic compensation for changes in liquid density. This is achieved through the use of a small buoy with an optical triangulation sensor for small displacements installed in it with a position-sensitive detector (Astapoz, 2021). The use of bellows for suspension of the buoy is theoretically justified, and the calculated absolute measurement error for the level of a petroleum product is less than ±1 mm. This makes these devices particularly suitable for applications that require high levels of accuracy and reliability.

2.3.2 Load Cells/Weighed-Based Sensor

Figure 2.9 shows a load cell. Load cells are transducers that convert mechanical force into an electrical signal. They are an integral part of many measurement systems due to their high accuracy, versatility, durability, ease of integration, non-intrusiveness, cost-effectiveness, and reliability. This essay delves into the working principle of load cells, their advantages, and their applications, particularly in monitoring fluid or water supply. The key component in a load cell is the strain gauge, a device that changes its electrical resistance in response to changes in strain or deformation.

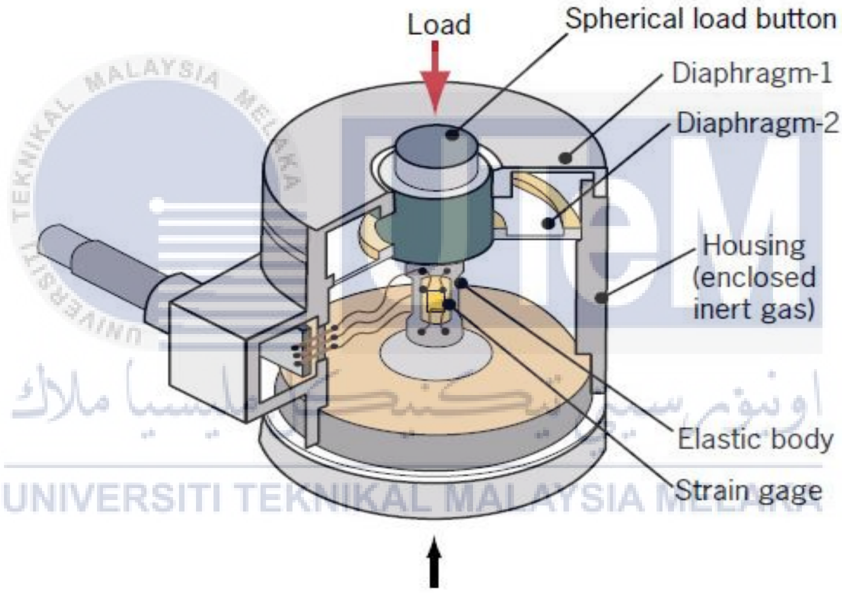


Figure 2.9: Strain Gauge Load Cell

When a load is applied to the load cell, it causes deformation in the strain gauge. This deformation changes the electrical resistance of the strain gauge. The change in resistance is proportional to the force applied, allowing the load cell to measure the force. The strain gauge is usually connected in a Wheatstone bridge configuration. A Wheatstone bridge is an electrical circuit used to measure an unknown electrical resistance by balancing two legs of a bridge circuit, one leg of which includes the unknown component.

This configuration allows for a highly accurate and reliable measurement of the change in resistance, and therefore the force applied. The electrical signal produced by the Wheatstone Bridge is typically very small, so it is amplified before being outputted. The amplified signal can then be read by an external device, such as a digital display or a computer, to provide a human-readable measurement of the force applied(Muller et al., 2021).

Load cells are known for their high accuracy. They can provide precise measurements of force or load, making them suitable for applications where precision is crucial. The accuracy of load cells can be as high as 0.03%, making them one of the most accurate devices available for force measurement. Load cells come in various types and sizes, which makes them versatile for different applications. They can measure force, weight, tension, compression, and more. This versatility allows them to be used in a wide range of industries, from manufacturing to healthcare. Load cells are typically made of robust materials like stainless steel or aluminum, which makes them durable and resistant to harsh conditions.

They can withstand heavy loads and can last for a long time with minimal maintenance. This durability ensures that load cells can provide reliable measurements over a long period. Load cells can be easily integrated into different systems. They can be connected to various devices like digital displays or computers for data reading and analysis. This ease of integration allows load cells to be used in complex systems without requiring significant modifications to the existing setup (Al-Dahiree et al., 2022).

Load cells provide non-intrusive measurements. They can measure the force or load without coming into contact with the material or object being measured. This is particularly useful in applications where contact with the material could lead to contamination or other issues. Load cells are relatively inexpensive compared to other measurement devices(Momin et al., 2019). They also require minimal maintenance, which makes them a cost-effective solution for long-term use. The cost-effectiveness of load cells is further enhanced by their durability and longevity, as they do not need to be replaced frequently. Load cells provide consistent and reliable measurements. They are not significantly affected by changes in temperature or humidity, which makes them reliable in various environmental conditions. This reliability ensures that load cells can provide accurate measurements even in challenging environments. Load cells are highly sensitive, allowing them to detect very small changes in force or load. This sensitivity allows them to be used in applications requiring high precision (Gaikwad & Dahikar, 2020).

2.3.3 Flow Rate Sensor

Mass flow rate sensors shown in Figure 2.10 and Figure 2.11 are a type of sensor that operates based on either inertia or thermal properties. Inertial meters, also known as Coriolis flow meters, use the Coriolis Effect to measure mass flow rate. When a fluid is flowing in a pipe and it is subjected to Coriolis acceleration through the mechanical introduction of apparent rotation into the pipe, the amount of deflecting force generated by the Coriolis inertial effect will be a function of the mass flow rate of the fluid. According to (Wong Kang, 2018) thermal mass flow meters, on the other hand, measure the mass flow rate of liquids and gases directly and function on the principles of heat transfer using a heating element and temperature sensors.

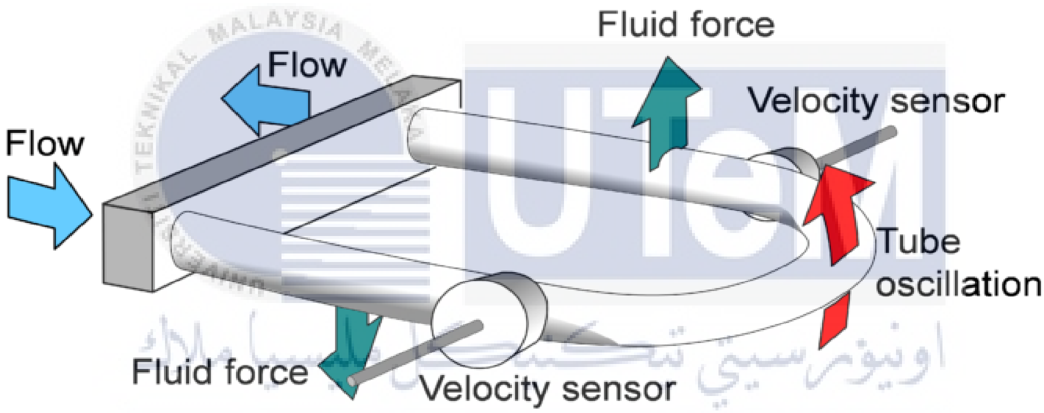


Figure 2.10: Mass Flow Rate Sensor

These sensors offer several advantages, including true mass flow measurement, additional temperature and density measurements, high accuracy for mass flow measurements, accurate density measurement, operation in both flow directions (forward and reverse), and immunity to changes in pressure, temperature, and viscosity (Secme, 2023). However, they also have some limitations. For instance, mass flow controllers require the supply gas or liquid to be within a specific pressure range. Low pressure will starve the MFC of fluid and cause it to fail to achieve its set point, while high pressure may cause erratic flow rates. Furthermore, these sensors are generally more expensive and require regular calibration to maintain accuracy.

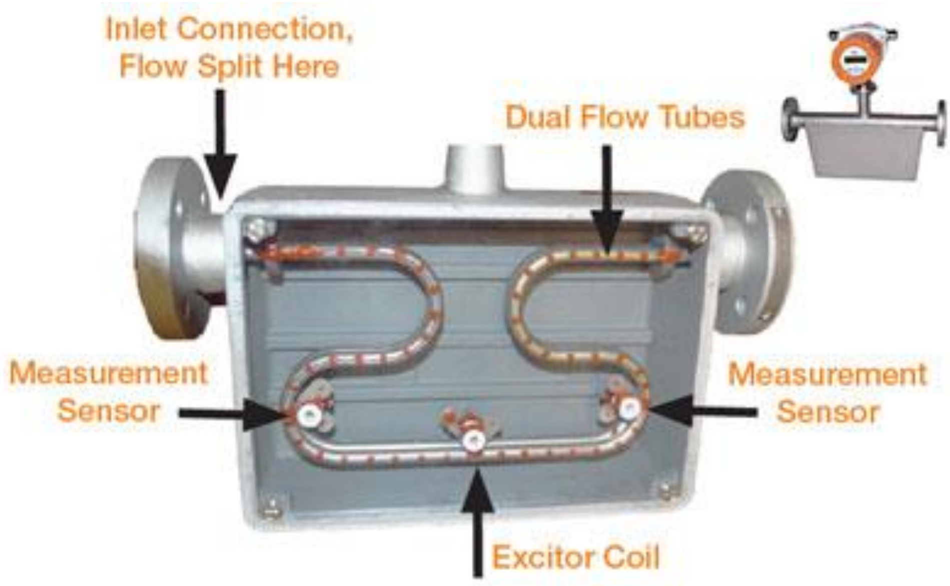


Figure 2.11: Mass Flow Rate

Recent research in the field of mass flow rate sensors has focused on the development of MEMS-based thermal mass flow sensors for high sensitivity and wide flow rate range. Another study proposes a method to detect Mass Flow Controller (MFC) defects in real time. The system monitors sensor data and Valve Open amount data, considering inlet pressure and MFC's temperature, which affect the flow rate and valve position. When the system monitors the Valve Open amount, the flow experiences problems such as flow contamination and thermal sensor drift. As a result, the system can detect the problem of the Mass Flow Controller.

The Paddle Wheel Flow Rate Sensor shown in Figure 2.12 operates based on the principle of fluid flow across a paddle wheel mechanism. The sensor, embedded within the paddle wheel, rotates freely when inserted into the fluid medium. The rotation of the paddle wheel, facilitated by the embedded magnets, generates a frequency and voltage signal proportional to the flow rate. The higher the fluid flow, the higher the frequency and voltage output.

The advantages of this type of sensor include its cost-effectiveness, ease of installation and operation, and the absence of pressure drop, making it ideal for gravity flows. Additionally, the design of the insertion flow meter reduces installation and maintenance costs. However, the Paddle Wheel Flow Rate Sensor also has several disadvantages. It is most effective with clean fluids, as particulates can hinder the paddle's rotation. It is not suitable for gases, requires a turbulent flow profile for accuracy, and necessitates a straight run of pipe before and after the flow meter. Furthermore, it may not function properly with high-viscosity fluids where the flow profile is laminar, and any air in the line may lead to inaccuracies.

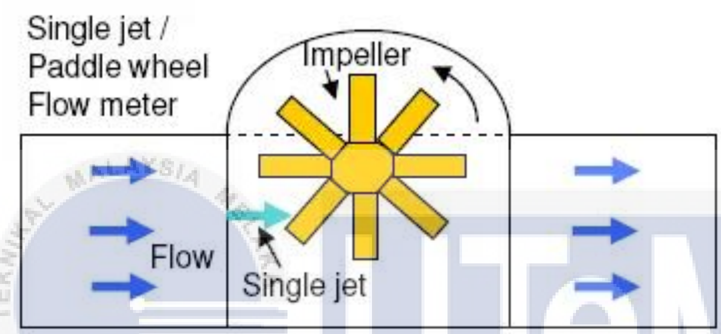


Figure 2.12: Paddle-Wheel Flow Rate Sensor

In terms of recent research, a study titled "Study on the reliability of paddle-wheel tumble flow meters for high-speed engines" was conducted by Massimo Masi, Lorenzo Artico, and Paolo Gobbato. The study assessed the reliability of the data obtained by a new paddle-wheel device, considering that the lack of the piston crown simulacrum could strongly affect the onset and intensity of tumble flow measured at the steady-state flow bench. The in-cylinder motion of two high-speed engine heads, as measured by the new paddle-wheel device, was compared with data from the literature, which was collected using traditional L- or T-junction tumble meters. The results demonstrated the reliability of the new device within the several limitations affecting such category of tumble meters.

Ultrasonic flow sensors shown in Figure 2.13 have been a topic of significant research interest due to their wide range of applications in various industries (Mingwei, 2010). The working principle of these sensors is based on the use of sound waves to determine the velocity of a liquid within a pipe. The sensor operates under two conditions: no flow and flowing. In the no-flow condition, the frequencies of ultrasonic waves transmitted into a pipe and their reflections from the fluid are similar. However, in the flowing condition, the frequency of the reflected wave differs due to the Doppler Effect.

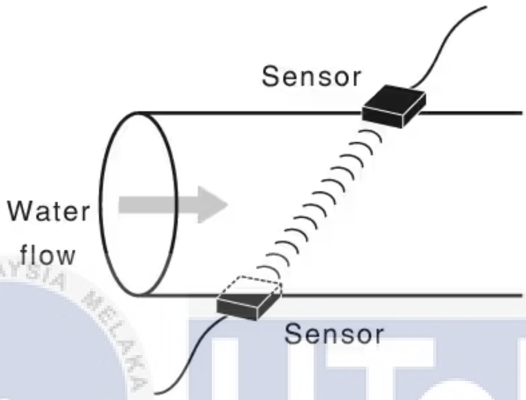


Figure 2.13: Ultrasonic Flow Rate Sensor

One of the main advantages of ultrasonic flow sensors is their ability to sense all types of materials. They are not affected by atmospheric dust, rain, snow, etc., and can operate under adverse conditions. Despite extensive research, no specific disadvantages have been identified in the search results.

Recent research has focused on improving the accuracy of ultrasonic flow measurement using different methods (Kumar, 2020). A comprehensive review on this topic was published, which discussed the use of reconfigurable systems and deep learning approaches for enhancing the accuracy of flow rate measurements. The study highlighted the importance of accurate flow rate measurements for the testing and reliable operation of engines in airborne vehicles, as well as in the food, automotive, and chemical industries.

The review also elaborated on the challenges associated with estimating the echo signal of the ultrasonic flowmeter and the necessity of real-time performance processing tasks for improving accuracy in flow rate measurements. The study proposed the use of field programmable gate arrays, digital signal processors, and other advanced processors, along with deep learning approaches, for improving the accuracy of flow rate measurements.

The review further discussed the reduction of uncertainty in single-path and multi-path ultrasonic flowmeters and suggested future research prospects for developing low-cost, reliable, and accurate ultrasonic flowmeters for a wide range of industrial applications. ultrasonic flow sensors offer a promising solution for accurate flow rate measurement in various industries. However, further research is needed to overcome the challenges associated with their use and to exploit their full potential.

2.3.4 Vision Sensor

The advent of vision sensors shown in Figure 2.14 has revolutionized the field of fluid level monitoring. These sensors, which use imaging technology to detect and measure the level of fluid in a container, offer a high degree of accuracy and reliability. Vision sensors, also known as optical sensors, use light, typically in the form of a laser or LED, to detect the presence and characteristics of an object(Beddiar et al., 2020). In the context of fluid level monitoring, these sensors can be used to detect the level of fluid in a container. The sensor emits a light beam, which is reflected off the surface of the fluid. The sensor then measures the time it takes for the light to return, which can be used to calculate the distance to the fluid surface, and hence the fluid level(Shahria et al., 2022).

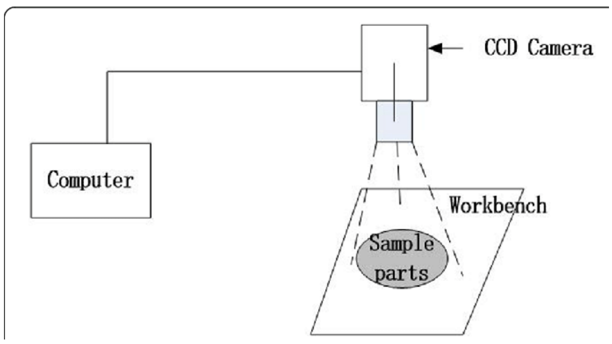


Figure 2.14: Example of Vision Sensor

One of the key advantages of vision sensors is their high degree of accuracy. Unlike traditional mechanical sensors, which can be affected by factors such as temperature and pressure, vision sensors are largely immune to these environmental variables. This means they can provide more reliable and accurate measurements. Additionally, vision sensors are non-contact, meaning they do not need to physically touch the fluid they are measuring. This makes them ideal for use in applications where the fluid may be corrosive or otherwise hazardous(Cho et al., 2022).

The integration of vision sensors into a fluid-level monitoring system typically involves selecting a vision sensor that is suitable for the specific application. This will depend on factors such as the type of fluid being measured, the size and shape of the container, and the environmental conditions. The sensor should be installed in a location where it can accurately detect the level of the fluid. This will typically be at the top of the container, looking down at the fluid surface. Once installed, the sensor will need to be calibrated to ensure it provides accurate measurements. This typically involves filling the container to a known level and adjusting the sensor's settings until it provides the correct reading. The final step is to integrate the sensor with the rest of the monitoring system. This will typically involve connecting the sensor to the system's control unit and configuring the software to interpret the sensor's readings.

CHAPTER 3 :
METHODOLOGY

This chapter describes the proposed methodology of this research which consist the principles of methods that will be performed to complete the research. The problem conceptualizationj, planning, designing, modelling and testing will be presented as well after refer attentively to the specification and particular of previous research. The main principle of this methodology is suggesting the suitable methods, recommended tool and techniques to complete this research.

The methodology for this research is structured to systematically address the objectives of improving the flux spraying process in through-hole PCB assembly. The approach involves multiple stages, each designed to ensure a thorough investigation and implementation of a fuzzy logic control system for enhanced precision and efficiency.

This structured methodology ensures a comprehensive and robust approach to enhancing the flux spraying process in electronics manufacturing, leveraging advanced control systems to achieve superior performance and reliability.

3.1 Flowcharts

The stages of research that will be taken in determining the next steps in the preparation of this research are as shown in Figure 3.1.

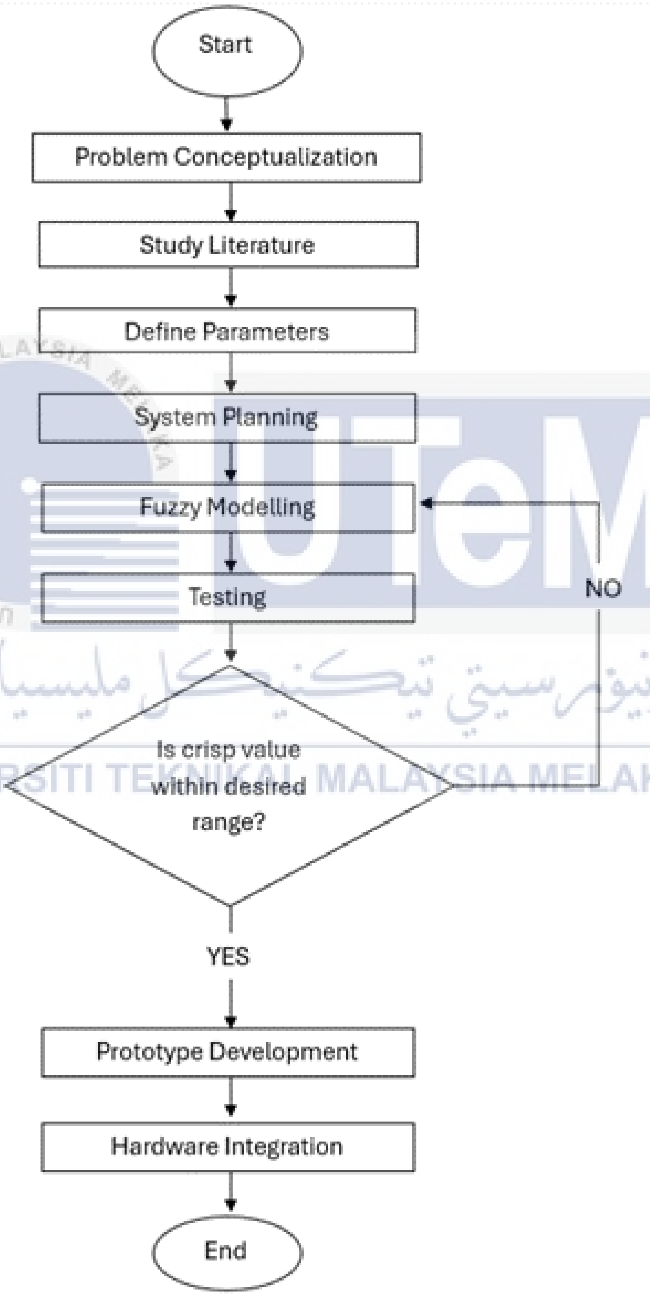


Figure 3.1: Methodology Flowchart

Figure 3.2 shows how the system will proceeds. Starting with the Data Load Cell and Data Flow Rate, the system gathers numerical input, which is then transformed into fuzzy sets during the Fuzzification stage. These sets are processed by the Inference Engine, which applies expert-provided rules from the Rule Base to derive conclusions. The resulting fuzzy set is then made into a crisp, actionable output through Defuzzification. A subsequent Check determines the quality of the output, classifying it as either Good or Bad. This classification is then indicated in the final step, signalling the end of the process.

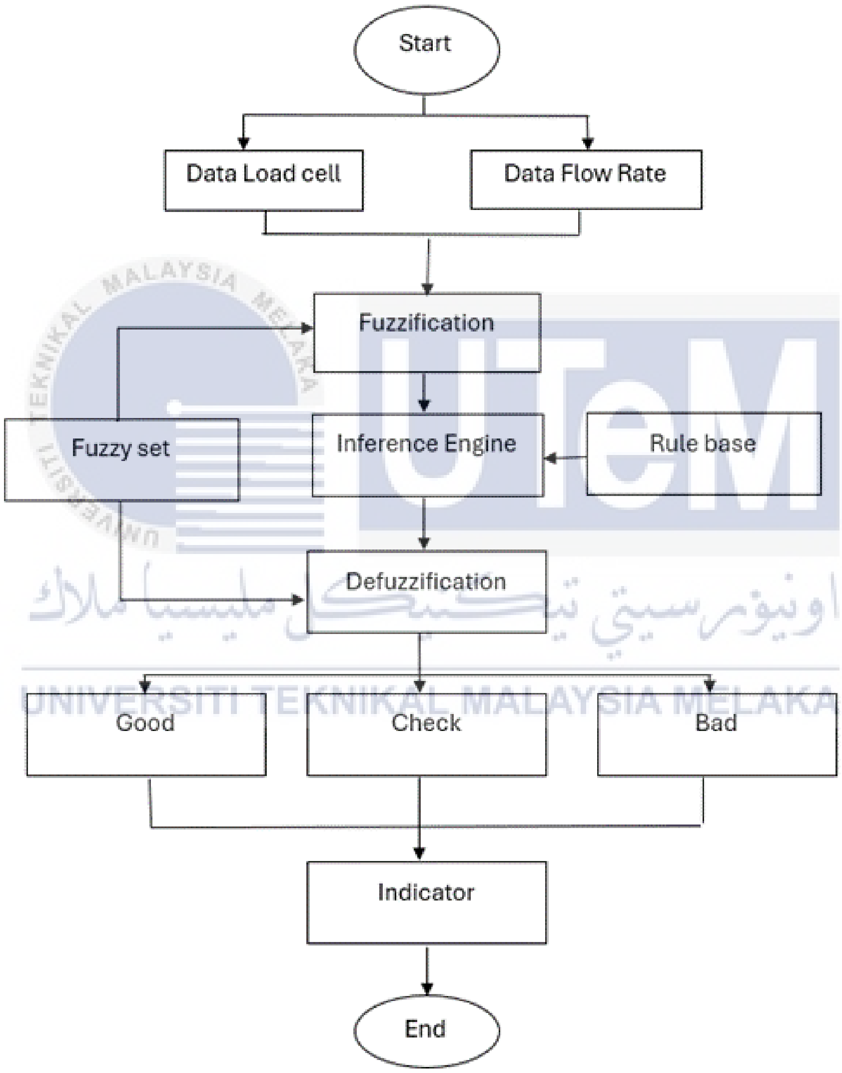


Figure 3.2: System Flowchart

3.2 Data Collection and Analysis

To achieve a comprehensive understanding of the current flux spraying process, specific data has been collected and analyzed. The key parameters include the weight of the flux container, flux flow rate, spray pressure, type and size of nozzle, desired flux thickness, operating temperature, and humidity. Additionally, properties of the flux such as density, viscosity, and surface tension are considered critical for a detailed analysis. Table 3.1 shows the data required for the analysis.

Table 3.1: Specification on Flux Spray Machine

Data		Unit	Value
Weight of Flux Container		Kg	20
Flux Flow Rate		ml/min	40 to 70
Spray Pressure		Bar	2-4
Type of Nozzle		-	Single needle
Size of Nozzle		-	1.3mm
Desired Flux Thickness. Weight		Microns(µm) Milligram (mg)	0.5 to 1gram
Operating Temperature		°C	25-30C
Operating Humidity		%RH	40-60
Flux Properties	Density	g/cm³	0.790 +/- 0.005
	Viscosity	Pa·s or cP	NA
	Surface Tension	N/m	>1.00 x 10^(8)

Monitoring the weight of the flux container provides insights into the consumption rate and potential wastage of flux material. This metric is crucial for determining the efficiency of flux usage and identifying any discrepancies in the expected versus actual flux consumption.

The flux flow rate, measured in grams per minute (g/min) or milliliters per minute (ml/min), directly impacts the uniformity and consistency of flux application. Variations in flow rate can lead to over- or under-coating, affecting the quality of the PCB assembly.

Spray pressure, recorded in bars, is a key parameter influencing the atomization of the flux and its subsequent deposition on the PCB. Proper control of spray pressure is essential to achieve the desired flux thickness and ensure thorough coverage of through-holes.

The type and size of the nozzle determine the spray pattern and droplet size of the flux. Selecting the appropriate nozzle configuration is critical for optimizing the flux distribution and minimizing waste.

The desired flux thickness, measured in microns (µm), is a target parameter that ensures sufficient flux coverage for effective soldering while avoiding excess buildup. Achieving the precise thickness is vital for maintaining the integrity of the PCB assembly.

Operating temperature (°C) and humidity (%RH) are environmental factors that can affect the flux properties and its application. These conditions must be controlled to ensure consistent flux performance and adherence to quality standards.

3.2.1 Flux Properties

Density (g/cm^3): The density of the flux affects its flow characteristics and spray behavior. A consistent density is important for predictable application results.

Viscosity (Pa·s or cP): Viscosity influences the ease of flow and atomization of the flux. Proper viscosity control is necessary to avoid clogging and ensure smooth operation.

Surface Tension (N/m): Surface tension impacts the wetting properties of the flux on the PCB surface. Optimal surface tension is required to achieve uniform coverage and adhesion.

3.3 Description of System

This section describes the simulated system designed to monitor flux supply in a flux spray machine using a fuzzy logic control (FLC) approach implemented within the MATLAB/Simulink environment. The system relies on two key sensor inputs to monitor the flux supply process:

a) Load Cell (Simulated): This simulated sensor represents the weight of the remaining flux material. By manipulating this input signal in Simulink, how changes in flux level impact the control system can be explored.

b) Flow Rate Sensor (Simulated): This simulated sensor represents the rate at which flux is dispensed from the machine. Similar to the load cell, it is possible to vary this input in Simulink to analyze the FLC response under different flow rate conditions.

These simulated sensors provide virtual data that the FLC system utilizes to maintain a consistent and controlled flux supply.Breakdown of the simulated system components within MATLAB/Simulink is as shown:

a) Flux Spray Machine Model (Simplified): This model represents the essential dynamics of the flux supply process, such as material flow and potential delays. The complexity of this model will depend on the specific focus of your project.

b) Sensor Blocks:

   i. Load Cell (Simulated): This block generates a signal corresponding to the weight of the remaining flux based on your defined parameters.

ii. Flow Rate Sensor (Simulated): This block generates a signal representing the flux flow rate based on your defined parameters.

iii. Fuzzy Logic Controller (FLC): This is the core of the system, implemented entirely within Simulink using fuzzy logic toolbox functions. It receives sensor data as inputs, processes it using fuzzy rules, and generates a control signal.

c) Control Interface (Simulated): This simulated interface translates the control signal from the FLC into a format suitable for manipulating the flux supply system in the model. It might involve adjusting a virtual valve opening or feeder speed within the model.

Benefits of using a Simulated System:

a) Controlled Environment: Simulink allows you to test and refine the FLC design under various operating conditions without the need for a physical prototype.

b) Flexibility: You can easily modify sensor inputs, fuzzy rules, and model parameters to explore different scenarios and optimize control performance.

c) Cost-Effectiveness: Utilizing simulation avoids the need for expensive hardware components during the initial design and testing phase.

3.4 Fuzzy Logic Control Design for Flux Supply Monitoring

This section details the design of your fuzzy logic control (FLC) system for monitoring flux supply in the flux spray machine simulation using MATLAB/Simulink. The FLC aims to provide an indicator that triggers a container change before the flux supply runs out, ensuring an uninterrupted process.

3.4.1 Input Variables:

Figure 3.3 shows the simulation setup in Simulink using different blocks to represent the process. Each block has a specific function in the simulation.

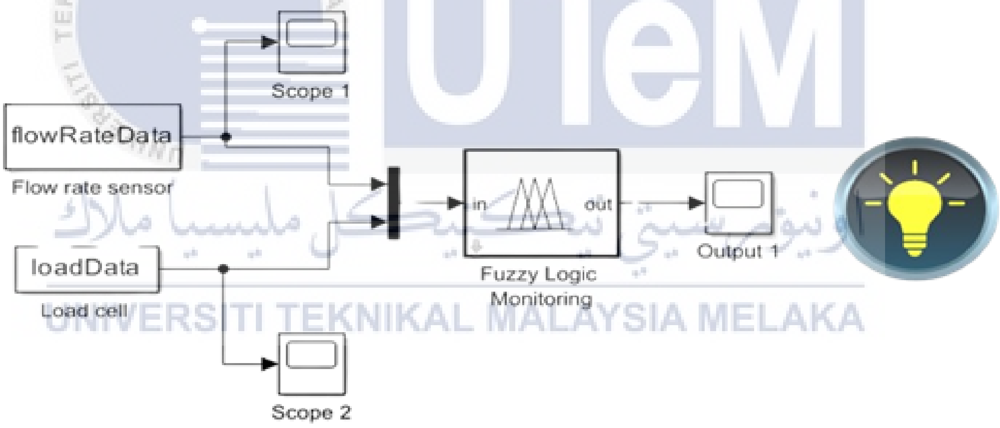


Figure 3.3:Simulation setup

As described in the system description, the FLC utilizes two sensor inputs:

a) Load Cell (Simulated): This input represents the weight of the remaining flux material. Define the range of this input based on the capacity of your simulated hopper and the corresponding weight units (e.g., grams, kilograms).

b) Flow Rate Sensor (Simulated): This input represents the rate at which flux is dispensed from the machine. Define the range of this input based on the expected operating range of your simulated delivery system (e.g., milliliters per second, liters per minute).

Figure 3.4 shows the overall input and output membership function of the fuzzy logic system

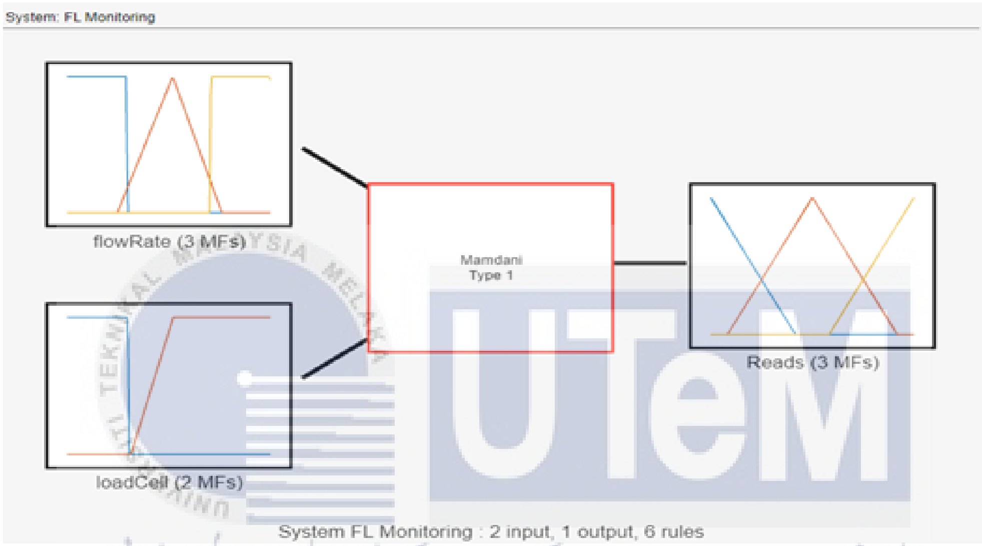


Figure 3.4:Input, Output FLC

3.4.2 Membership Functions:

Membership functions translate the crisp sensor data (load cell weight, flow rate) into linguistic variables that the FLC can understand. Here, you can choose appropriate membership functions to represent the level of remaining flux and the flow rate.

Load Cell membership functions, shown in Figure 3.5, like "High," "Medium," and "Low" represent the weight of the remaining flux. "High" indicate a sufficient amount for continued operation, "Medium" signify a need to prepare for a container change soon, and "Low" represent a critically low level requiring immediate action.

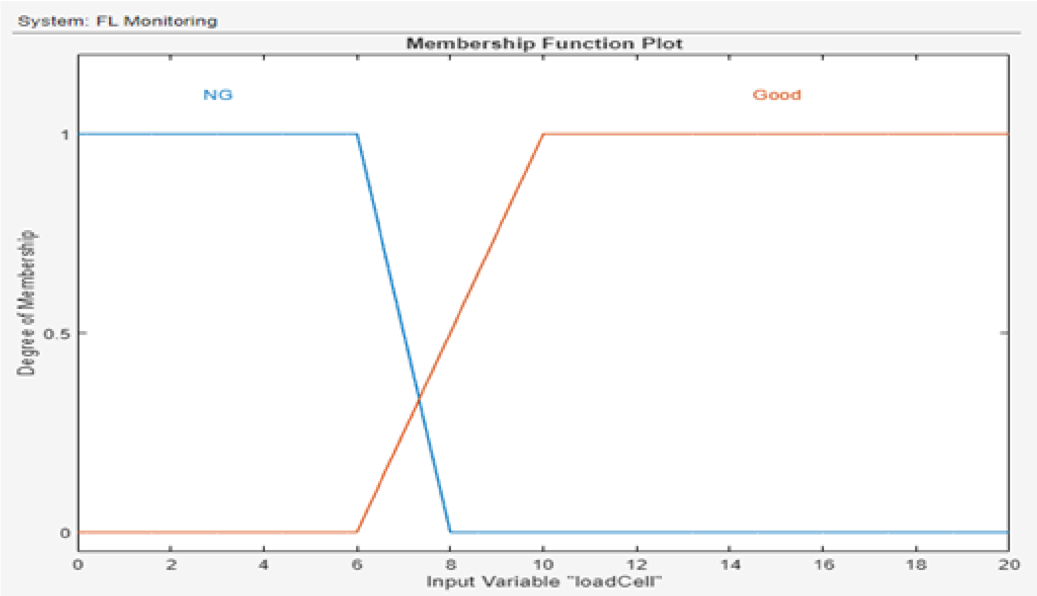


Figure 3.5: LoadCell Input

Flow Rate membership functions, shown in Figure 3.6, like "Normal" and "High" are used for the flow rate. "Normal" represent the expected operating flow rate, and "High" indicate a potential surge in consumption that might deplete the remaining flux faster than anticipated.

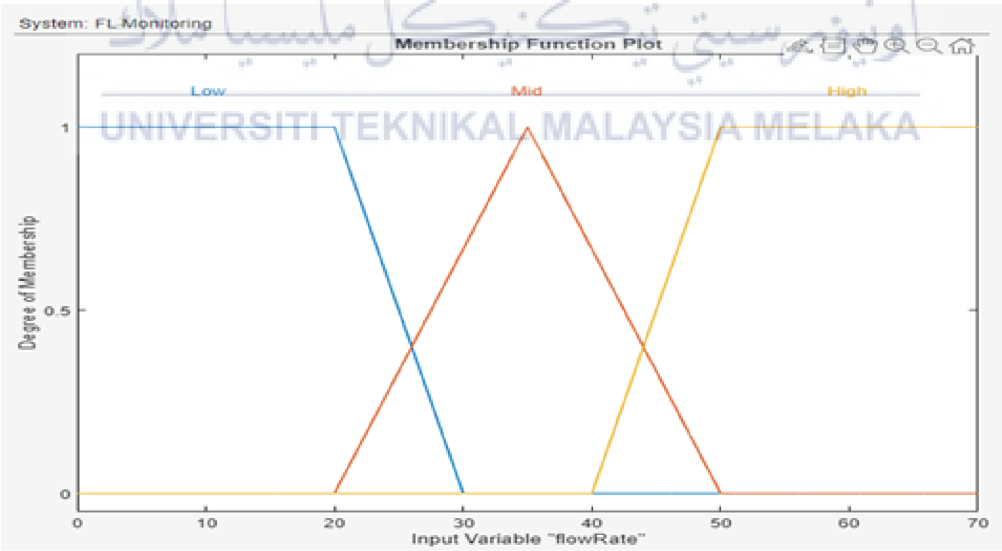
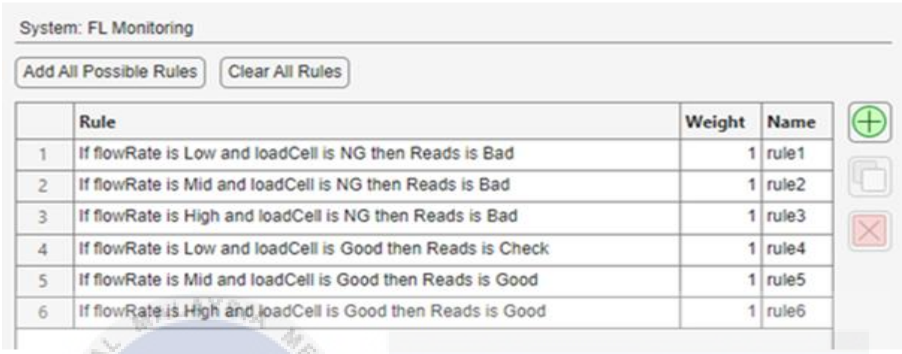


Figure 3.6:FlowRate Input

3.4.3 Fuzzy Rules:

Developed a set of "If-Then" rules based on expert understanding of the flux supply process and the desired indicator output ("Good," "Check," "Bad"). For example, as shown in Figure 3.7.



	Rule	Weight	Name
1	If flowRate is Low and loadCell is NG then Reads is Bad	1	rule1
2	If flowRate is Mid and loadCell is NG then Reads is Bad	1	rule2
3	If flowRate is High and loadCell is NG then Reads is Bad	1	rule3
4	If flowRate is Low and loadCell is Good then Reads is Check	1	rule4
5	If flowRate is Mid and loadCell is Good then Reads is Good	1	rule5
6	If flowRate is High and loadCell is Good then Reads is Good	1	rule6

Figure 3.7: Inference Rules

- Rule 1: If Load Cell is "High" AND Flow Rate is "Normal," Then Indicator is "Good" (sufficient flux for continued operation).
- Rule 2: If Load Cell is "Medium" AND Flow Rate is "Normal," Then Indicator is "Check" (prepare for container change soon).
- Rule 3: If Load Cell is "Low" OR Flow Rate is "High," Then Indicator is "Bad" (immediate container change required).
- Rule 4: If Load Cell is "Medium" AND Flow Rate is "High," Then Indicator is "Bad" (urgency due to potentially high consumption rate).

Table 3.2: Input of Flow Rate and Load cell and Output of Readings

	NG	Good
High	Bad	Good
Mid	Bad	Good
Low	Bad	Check

Table 3.2 shows an established comprehensive set of rules that consider various combinations of input conditions to ensure the indicator accurately reflects the flux supply status and triggers a container change before depletion.

3.4.4 Output Variable:

Figure 3.8 shows the output of the fuzzy logic labelled as “Reads”.

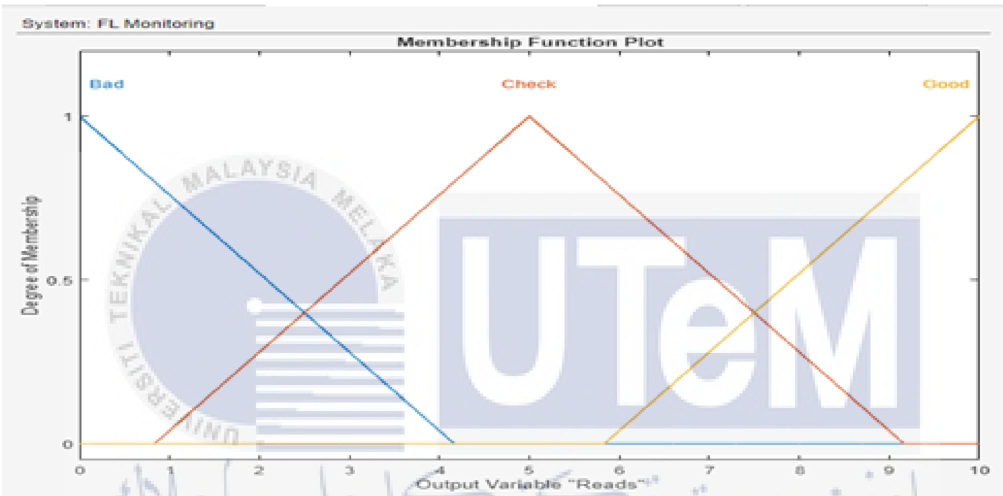


Figure 3.8: Reads Output

The FLC output is the indicator signal with three possible states:

a) Good: Indicates a sufficient amount of flux remaining for continued operation.

b) Check: Signals a need to prepare for a container change soon to avoid disruption.

c) Bad: Requires immediate action to replace the depleted or near-depleted flux container.

3.4.5 Defuzzification:

Calculation Of Centroid for Defuzzification

$$g = \frac{\sum_{i=1}^{n} x_i \cdot u(x_i)}{\sum_{i=1}^{n} u(x_i)}$$

- $\sum_{i=1}^{n} x_i$ is the membership value at point(x_i).
- (x_i) is a specific value within the universe of discourse.
- The summation Σ_i runs over all discrete points i of the fuzzy set.

In simpler terms, you multiply each value (x_i) by its corresponding membership degree $\sum_{i=1}^{n} x_i$, sum all those products, and then divide by the sum of all membership degrees. This process finds the "balance point" of the fuzzy set, providing a single crisp output value.

This method is analogous to finding the center of mass of an object in physics, where the centroid is the point where the object would balance perfectly if it were to be placed on a pivot. In the context of fuzzy logic, it provides a way to reason with imprecise or fuzzy information and arrive at a precise action or value.

Similar to the previous version, the final step involves converting the fuzzy output (a collection of membership degrees for different indicator states) into a crisp output signal suitable for the simulated system. Common defuzzification techniques can be employed within MATLAB/Simulink.

CHAPTER 4 :
RESULTS AND DISCUSSION

This section evaluates the performance and effectiveness of the proposed fuzzy logic monitoring system for flux supply in PCB production. The results are derived from simulations conducted using MATLAB and Simulink environments. The fuzzy logic control system's behaviour was analysed through various scenarios, testing its ability to maintain continuous flux supply and prevent interruptions.

4.1 Crisp Value Analysis

The crisp value analysis is a crucial step in evaluating the performance of the fuzzy logic control system. In Figure 4.1, by applying specific, non-fuzzy input values to the system, assessment on how well the system processes and responds to real-time data is done. This section discusses the results of applying crisp values of 40.6 for the flow rate and 12.8 for the load cell, which produced an output of 8.5 on the Read variable.

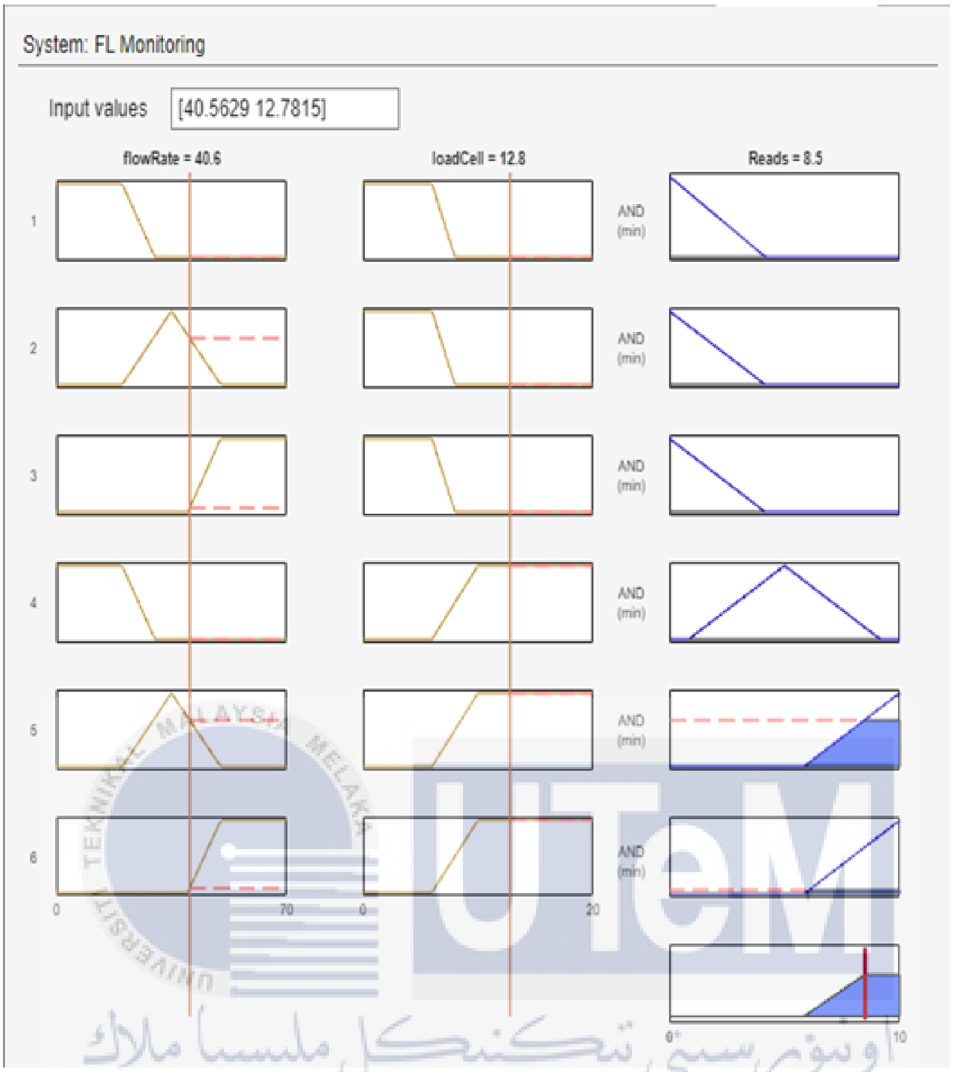


Figure 4.1: Rule Viewer

4.1.1 Input Variables and Membership Functions

Flow Rate (40.6):

The flow rate input is processed through six different membership functions, each representing a linguistic variable such as Low, Medium, High. The crisp value of 40.6 is evaluated against these membership functions, resulting in different degrees of membership (depicted by the red vertical lines intersecting the curves).

Load Cell (12.8):

Similarly, the load cell input is evaluated using six membership functions. The crisp value of 12.8 generates degrees of membership across these functions, indicating how closely the input matches each linguistic variable.

4.1.2 Rule Evaluation and Firing

Fuzzy Rule Base:

The fuzzy logic controller utilizes a set of predefined rules to determine the output based on the input values. Each rule is an IF-THEN statement combining the flow rate and load cell conditions. Example: "IF FlowRate is High AND LoadCell is Medium THEN Read is Moderate."

Rule Firing:

The degrees of membership for the input values determine which rules are fired. In this case, the flow rate of 40.6 and load cell of 12.8 activate specific rules that collectively influence the final output. The rule firing process is visualized in the diagram, showing how each input membership function contributes to the output.

4.1.3 Output Calculation and Defuzzification

Aggregating Outputs:

The outputs from the fired rules are aggregated to form a composite fuzzy output. Each rule contributes a portion of the output, which is combined using fuzzy operators like AND (min) and OR (max). The resulting fuzzy output is a combination of membership functions representing the Read variable.

Defuzzification:

The final step in the fuzzy logic process is defuzzification, where the aggregated fuzzy output is converted into a crisp value. In this analysis, the defuzzification process yields a crisp output of 8.5 for the Read variable. This value is derived using methods such as the centroid or mean of maxima, ensuring an accurate representation of the system's response to the input conditions.

4.1.4 Engineering Implications

System Responsiveness:

The ability of the fuzzy logic controller to process crisp input values and produce a precise output demonstrates its responsiveness and accuracy. This capability is critical for real-time applications where quick and accurate decisions are necessary. The analysis shows that the system effectively handles variations in input conditions, maintaining reliable performance.

Robustness and Reliability:

The evaluation of crisp values highlights the robustness of the fuzzy logic system. By accurately mapping input values to appropriate outputs, the system ensures consistent performance under different operating scenarios. This robustness is essential for applications in industrial automation, process control, and other fields where reliability is paramount.

Real-Time Data Processing:

The fuzzy logic controller's ability to process real-time data and react accordingly is a significant advantage. It allows for dynamic adjustments and immediate responses to changing conditions, enhancing the overall efficiency and effectiveness of the system. The crisp value analysis serves as a validation of the system's real-time processing capabilities, ensuring it can handle live data streams without compromising on performance.

4.2 Control Surface and Simulation

The controls surface of the fuzzy logic system was visualized in Figure 4.2, illustrating how different combinations of input variables influence the output. The MATLAB workspace hosted the fuzzy logic monitoring system, and the corresponding circuit diagram was constructed in Simulink to test the results.

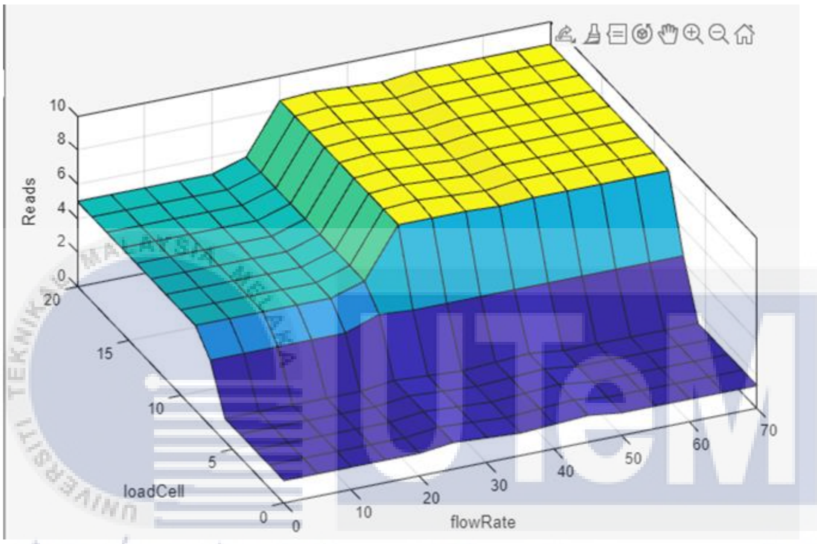


Figure 4.2:Control Surface Diagram

The control surface is a three-dimensional plot where:

a) X-axis (FlowRate): Represents the rate of flow, measured in suitable engineering units (e.g., millilitres per minute).

b) Y-axis (LoadCell): Corresponds to the load cell readings, indicative of the tank's weight or the load applied, also in appropriate units (e.g., kilograms or newtons).

c) Z-axis (Response): Shows the output of the fuzzy logic system, reflecting the system's operational status or performance metric.

4.2.1 Key Regions and Their Significance

Stable Regions:

These are characterized by large, flat areas on the control surface. Flat regions indicate a broad operational envelope where the system maintains optimal performance. The robustness of the system in these regions suggests it can handle variations in flow rate and load without necessitating immediate adjustments or interventions. This stability is critical for ensuring consistent system performance and reliability under normal operating conditions.

Transition Regions:

These regions are where the surface begins to incline from a stable state to a higher response level. Transition regions are indicative of the system's sensitivity to changes in input variables. They represent critical zones where the system starts to deviate from the stable state, necessitating closer monitoring and potential adjustments. These regions are crucial for pre-emptive diagnostics, allowing for timely interventions before the system reaches critical conditions. Early detection in these zones can prevent system failures and ensure continuity of operation.

Critical Regions:

These are peaks on the control surface where the response reaches its maximum or minimum values. Peaks in the control surface signify conditions where the system's performance is at risk, indicating potential operational hazards. These critical regions are where the fuzzy logic system flags high-risk scenarios, requiring immediate attention. In engineering terms, these zones are vital for defining safety thresholds and automated response mechanisms. Ensuring robust alarm systems and intervention protocols in these regions can mitigate risks and maintain system integrity.

4.2.2 Interpretation and Usage

The control surface aids in fine-tuning the fuzzy logic system parameters, ensuring optimal performance across all operating conditions. By analysing the surface, engineers can identify and reinforce stable regions while minimizing the transition and critical regions through system redesign or parameter adjustments.

The clear delineation of transition and critical regions supports the development of predictive maintenance schedules. By continuously monitoring the inputs and corresponding outputs, potential issues can be anticipated and addressed proactively.

Understanding the control surface allows for the implementation of robust safety protocols. Automated alerts and intervention strategies can be designed to activate when the system approaches critical regions, thereby enhancing overall safety and reliability.

4.3 MATLAB Workspace

The input versus output data for the fuzzy logic control system were plotted and illustrated. This visualization helps in understanding the system's response under various conditions and validates the fuzzy logic model's effectiveness. The fuzzy logic control system has been transferred to the MATLAB workspace under the name “Fuzzy Logic Monitoring”. Then the corresponding circuit diagram has been built in Simulink to test the results. The two inputs multiplexer has been constructed. The inputs are being fed into the system in the forms of Math Function. The order of the inputs must be same as the order of the input’s variables being constructed in MATLAB. The values have been fed into the system for flow rate and load cell. The outputs from the system also should keep the order when being constructed in fuzzy logic controller toolbox. The Simulink model is illustrated in Figure 4.3**.** The output Read also is connected to Lamp Block to demonstrate LED Indicator.

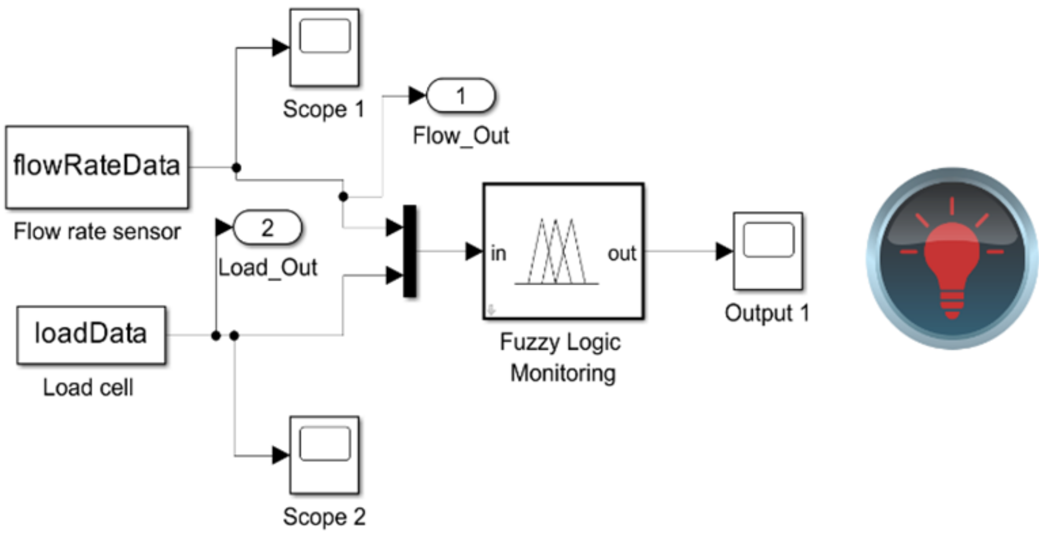


Figure 4.3: Finalise Simulink Setup

The results indicate that the fuzzy logic monitoring system was simulated correctly. The MATLAB rule viewer confirmed accurate defuzzification computations, aligning well with the crisp values applied during testing. The Simulink simulation yielded results consistent with those obtained from the fuzzy logic controller toolbox, further validating the system's accuracy and reliability.

These findings suggest that the fuzzy logic monitoring system successfully maintains an uninterrupted flux supply in PCB production, thus minimizing downtime and enhancing productivity. The system's ability to predict and alert for flux replenishment proves its potential as a significant improvement over traditional monitoring method.

CHAPTER 5 :
CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The first objective of this research is to analyse the current process of flux spraying in through-hole PCB production. The detailed assessment of the current flux spraying process revealed several key areas for improvement. The analysis showed that inconsistencies in spray pressure, flux flow rate, and environmental conditions (temperature and humidity) significantly impact the uniformity and reliability of flux application. Variations in these parameters lead to over- or under-coating, increased material waste, and higher defect rates in PCB assemblies.

The second objective of this research was to design a fuzzy logic control system to monitor the fluid supply for flux spraying process. The significant conclusions for this objective are as follows:

(a) The fuzzy logic control system was successfully designed and implemented using MATLAB Fuzzy Logic Designer. This system dynamically adjusts and monitors the fluid supply parameters based on real-time data, ensuring a consistent and optimal flux application throughout the PCB production process.

(b) The fuzzy logic control system proved to be highly effective in maintaining the desired fluid supply levels, thereby preventing interruptions and ensuring continuous operation. The system's ability to adjust to fluctuations in supply parameters minimized material waste and reduced the likelihood of defects, resulting in increased production efficiency.

The third objective of this research was to validate the newly designed fuzzy logic control system through MATLAB/Simulink simulation. The significant conclusion for this objective is that the newly designed fuzzy logic control system showed high accuracy in maintaining optimal fluid supply levels and adjusting spraying parameters. The simulation results indicated a significant reduction in variability and defects, highlighting the system's reliability in producing consistent and high-quality PCB assemblies.

5.2 Recommendations

After gone through this research, there are few recommendations suggested so be able to call attention to the important aspect need to be focus on for coming research topic about gelcoat in the future.

(a) Develop and test advanced predictive algorithms that combine fuzzy logic with machine learning techniques. This hybrid approach could potentially improve the accuracy of flux depletion predictions and further reduce system downtime.

(b) Explore the integration of the fuzzy logic monitoring system with Industry 4.0 technologies such as the Internet of Things (IoT) and big data analytics. This could enable real-time data collection and analysis from multiple sources, leading to more robust and adaptive flux monitoring solutions.

(c) Investigate the application of the fuzzy logic monitoring system in other critical processes within PCB manufacturing, such as solder paste application and component placement. This could help generalize the system's utility and demonstrate its versatility in various production stages.

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BMIU 4924 PROJEK SARJANA MUDA II

Correction Table Format (This form must be submitted together with the final report)

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ITEM	CORRECTION REQUIRED	AMENDMEND DONE	OLD PAGE NUMBER	NEW PAGE NUMBER
Title				
Abstract	**Uses of Past/Present Tense**	**Use of Past Tense**		
Formatting (citation etc.)	**Figure and Table numbering**	**Change to 1.1, 2.1 for figure and table numbering**		
Chapter 1 (List down your corrections in numbering format)				
Chapter 2 (List down your corrections in numbering format)				
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Chapter 5				

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List of References				
Extra chapters (optional)				

Supervisor's comments:

No comment

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