Latex Glove Samples Cutting System with Fuzzy Controller

J. L. Tan, K.S. Sim, E. K. Wong, and Y. H. Ow

Abstract- **Latex glove usage has increased significantly in the medical field since it provides protection for both the patient and the medical professional. However, the latex contains numerous types of protein which can cause allergic skin reaction to its user. Therefore protein concentration test is needed to determine the biocompatibility of latex gloves. Normally, samples are cut from a latex glove for the test. In this paper, we describe the fuzzy controller design of the glove sample cutting system. In this work, the glove is cut into seven square samples of dimension 2 cm by 2 cm each. A 4-axis computer numerical control (CNC) cutting machine is designed and constructed for this purpose. The challenge is that latex gloves in the market come with different thicknesses and sizes. Therefore, a fuzzy controller for latex glove (FCLG) is applied to determine the most optimal cutting parameters for the cutting process to overcome the challenge of different thicknesses and sizes. The cutting template is one of the ~~lead~~ factors that affect the sample cutting result. Three types of cutting templates are used to examine the most suitable material for the cutting process. The FCLG is implemented using a general-purpose microcontroller. Results showed that FCLG has significantly improved the cutting process and the outcome of the samples. Several cutting tests are performed to ensure that the samples are detached completely with accurate sizes. The latex glove samples cutting system with the fuzzy logic controller has improved the cutting success rate from 42.86% to 82.54%. The accuracy has improved from 59.75% to 82.98%.**

Index Terms—**cutting system, fuzzy controller, glove industry, latex glove**

I. Introduction

The latex gloves were invented in 1889 to prevent dermatitis [1], [2]. Nowadays, latex gloves are used in a variety of industries due to its excellent protection to the skin. The Natural Rubber Latex (NRL) is the primary material for latex gloves, and it is derived from the sap of the rubber tree [3]. Latex contains hundreds of proteins, and some of these protein fractions are responsible for allergic reactions. Itching, runny nose, or asthma are some of the allergy symptoms that may be caused by latex. Symptoms such as itching, redness, and swelling can occur when allergic skin comes in contact with latex proteins [4]. The Color Kernel Regression Method (CKR) technique is used to determine the protein concentration in the latex gloves [5]. This protein detection method involved several manual processes such as samples cutting, binding and scanning [6]. The patented latex glove cutting machine (PI 2019002679) is operated manually and with low efficiency [7], [8]. Thus, a fuzzy controller for latex glove (FCLG) is developed to improve the cutting performance. However, the subsequent processes for the protein detection method remain manual processes.

According to the goal of Industry Revolution 4.0, the industry needs to focus on automation process improvement and productivity optimization. In other words, the accuracy and time taken to perform an operation are becoming the most critical aspects of the industry today. However, the steps in quantifying the protein concentration in latex gloves are very complicated [9] and labour intensive [10]. In order to ease the protein detection test, a specific glove sample size of dimension 2 cm by 2 cm is needed. The process of cutting out this sample from the glove is normally carried out manually and hence it is very time-consuming.

This work proposes an intelligent system, namely FCLG to overcome these issues. This work investigates the most suitable cutting platform template for the glove and evaluates the accuracy and success rate in terms of the final sizes of the glove samples.

Section II of this paper provides the reviews of the related works. The design of the FCLG cutting machine with double cutter actuators are described in Section III. The experimental results, system performance analysis and conclusions are presented in Sections IV and V respectively.

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II. Related Research Works

A. Glove Samples Position

Latex is a natural product that comes from rubber trees, and its quality has a direct impact on the quality of the glove produced [11]. Several factors, such as terrible factory conditions and latex that is not properly centrifuged, may cause latex protein allergy. The conventional way of biocompatibility test for latex glove is by dipping the whole glove into the Lowry reagent, and this method needs 5 to 6 hours to obtain results [8], [12]. Another method is to cut the glove into seven pieces with each of them having sample size of 2 cm by 2 cm to ease the protein detection process. Five samples are cut from each of the fingertips, and two samples are from the palm area as shown in Fig. 1 [13], [14]. The fingertips positions are selected because most of the protein remained on the fingertips after the dipping process in the glove production [15], [16]. These positions also represent the most touch areas for the users.

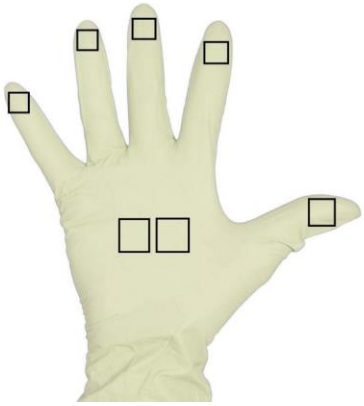

Fig. 1. Samples Cut Position

The processes of the CKR (Color Kernel Regression) method is shown in Fig. 2.

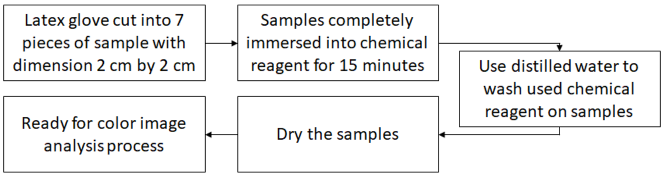

Fig. 2. Existing Protein Detection Processes

The patented latex glove samples cutting system that used this method operates with the conventional proportional–integral–derivative (PID) controller [7]. It used the Arduino MEGA 2560 microcontroller to control the stepper motors for cutting point direction with adjustment. A platform using a magnetic sheet functioned as the cutting template. However, the system is unable to achieve a full seven samples cutting consistently. This is because different brands of latex gloves have different thicknesses while the system only has a fixed cutting depth.

B. Fuzzy Logic Overview

Fuzzy logic is described as the recapitulation of conventional logic and it is an advanced tool of Boolean logic with more than two possible results. For instance, an object can have a truth value of 0.6, and its complement can have a truth value of 0.4 or in a few categories like ‘yes’, ‘possibly yes’, ‘cannot say’, ‘possibly no’ and ‘certainly no’. The sum of all the truth values must not be equal to 1 [17]. Fig. 3 shows the difference between Boolean logic and fuzzy logic.

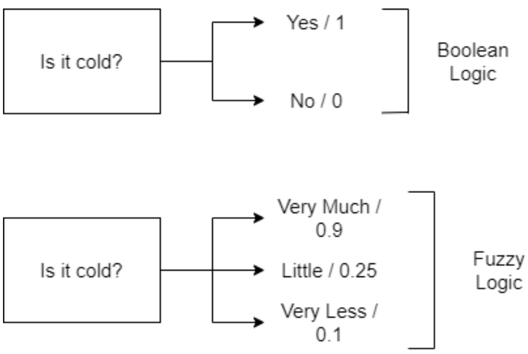

Fig. 3. Difference between Boolean Logic and Fuzzy Logic

There are four main components in fuzzy logic. They are rule base, fuzzification, inference engine, and defuzzification [19]-[21]. If-else rules provided by the users are stored in the rule base. Generally, two or more rules are used in the decision-making system. The inputs are usually the measurement of the components or values from the sensors, such as temperature and intensity [22]. These crisp inputs are then converted into the fuzzy sets by the fuzzifier. The inference engine acts as the artificial intelligence, which can stimulate the human reasoning process by considering the rule base and inputs. Lastly, the defuzzifier transforms the fuzzy set from the inference engine into a crisp output. Fig. 4 shows the flow chart of a fuzzy logic architecture.

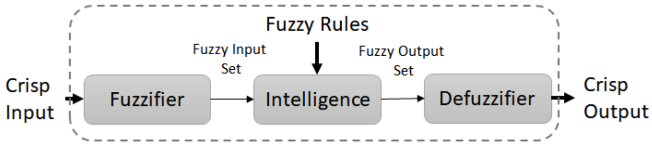

Fig. 4. Fuzzy logic Architecture

There are few methods to transform crisp inputs into the fuzzy sets. The most common methods are either applying the triangular membership function or trapezoidal membership function [23]. These two functions are relatively simpler to implement and analyze. The triangular membership function and trapezoidal membership function are shown in Fig. 5 and Fig. 6, respectively.

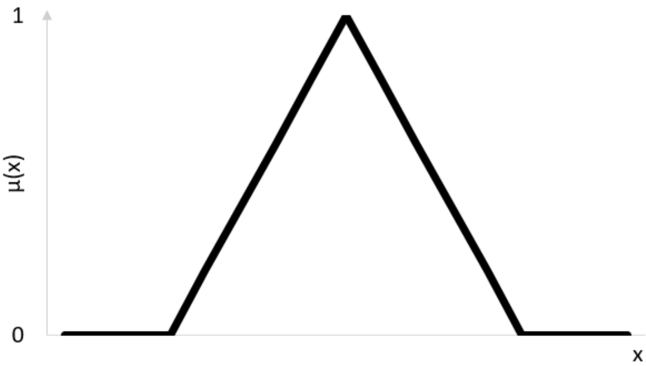

Fig. 5. Triangular Membership Function

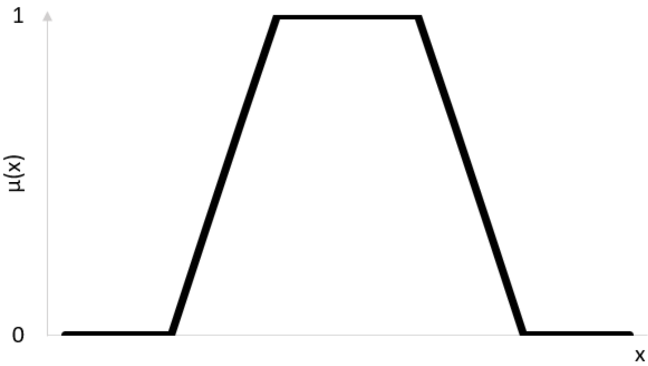

Fig. 6. Trapezoidal Membership Function

Another type of membership function is the Gaussian method [24]. This membership function has a smooth curve on the graph that provides the non-zero value at all the point and it is much more complicated as compared to the triangular and trapezium-shaped membership function [25]. Fig. 7 shows the Gaussian membership function.

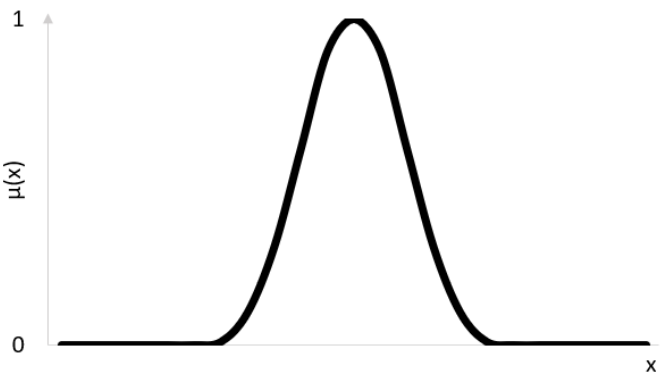

Fig. 7. Gaussian Membership Function

The fuzzy sets generated from the inference engine are not able to be used directly to the application. The defuzzifier is transforming the fuzzy sets into the crisps number output through the defuzzification process for further operation. There are numerous types of defuzzification, and the three most popular methods are the weighted average method, maxima methods, and centroid methods.

The weighted average method is very popular due to its high efficiency and effectiveness [26]. The output from each maximum membership value is used to form the solution. This method is only suitable for symmetrical membership function [27]. An example is shown in Fig. 8 and the corresponding equation is defined as (1).

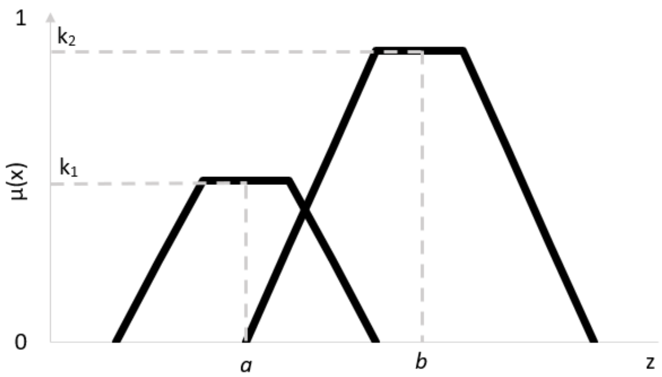

Fig. 8. Weighted Average Method

$$z = \frac{a(k_1) + b(k_2)}{k_1 + k_2} \tag{1}$$

a represents the mean value for the first membership function, and b represents the mean value for the second membership function according to the x-axis. k_1 and k_2 are the maximum mean value according to the y-axis. The z represents the calculated value, the fuzzy set defuzzified output.

Another popular defuzzification method is the mean max membership. As the maximum point of membership for other methods is a single point, the maximum point for this method can be a flat surface. Fig. 9 shows the mean max membership of defuzzification method, and an algebraic expression is used to represent the defuzzified value as shown in (2).

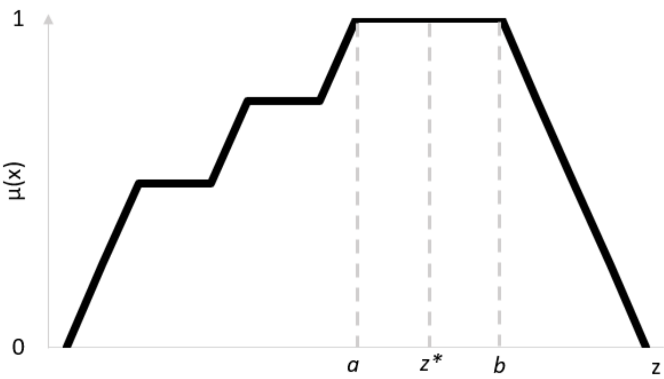

Fig. 9. Mean Max Method

$$z = \frac{a + b}{2} \tag{2}$$

From (2), a represents the lower limit of the membership function, and b represents the upper limit of the membership function. Based on the value of a and b, the defuzzified output, z is calculated.

III. Design of Fuzzy Controller For Latex Glove (FCLG)

The system described in [7] is a sample preparation unit for a protein concentration detection system. However, the system is unable to cut the sample completely in some cases. Therefore, a new fuzzy controller is designed to replace and improve the previous system. The designed latex glove samples cutting system with FCLG is shown in Fig. 10.

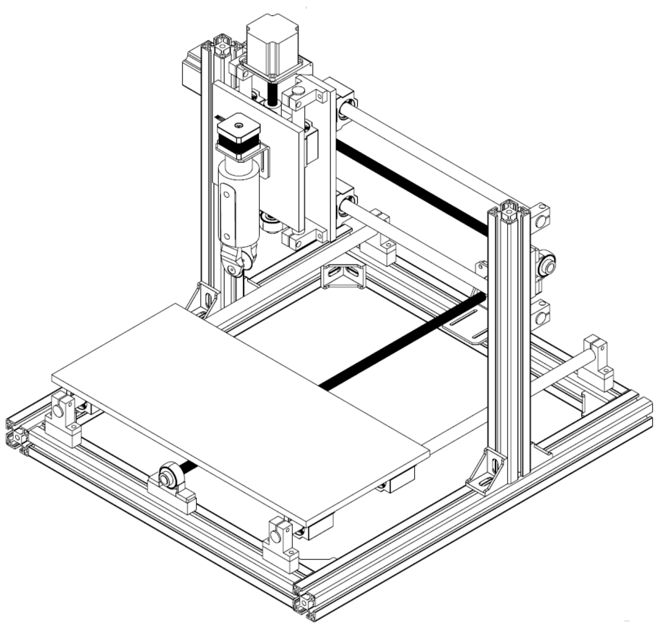

Fig. 10. Design of Latex Glove Samples Cutting System with FCLG

Base on the latex glove cutting system, a cutting actuator is designed to achieve the FCLG requirement. In this paper, the cutting actuator consists of two rotary cutters that are attached with a 14 mm radius circular blade each. This double cutter actuator design can simplify the cutting process and shorten the time required by half compared to single actuator. The design and fabricated actuator is shown in Fig. 11 and Fig. 12 respectively.

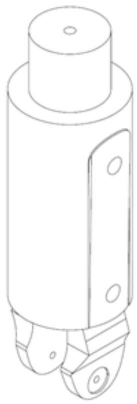

Fig. 11. The Design of the Double Cutter Actuator

Fig. 12. The Fabricated Double Cutter Actuator

There are two inputs and one output for the FCLG. The inputs are the thickness of the glove and the hardness of the cutting template. The output is the depth of the cutting process.

Based on these parameters, the controller system is developed using stepper motors with controllable moving mechanism. In this paper, an Arduino MEGA 2650 is used as the main microcontroller [28] for the system, and the S109 driver is used to control the stepper motor [29]. Its cooling effect is excellent due to the attached. The designed FCLG firmware is applied to the existing latex glove samples cutting system. This system only requires a single worker to place the glove on the cutting template at the beginning of the cutting process. The FCLG will perform the subsequent cutting process automatically to produce seven pieces of glove samples.

Several types of membership functions are used to develop the desired fuzzy logic controller [30], [31]. The triangle membership function is used as the fundamental membership function. Based on the basic triangular membership function, several FCLG membership functions are designed with the system parameters. There are a total of three membership functions for the inputs. The inputs are the thickness of the glove, the hardness of cutting template and the output the cutting depth. These parameters are defined as the linguistic variables [32]. The linguistic variables used for the latex glove cutting system are shown in Table I.

TABLE I
LINGUISTIC VARIABLES

	Parameters	Linguistic Variables
Input	Thickness of Glove	Thin, Average, Thick
	Hardness of Template	Soft, Medium, Hard
Output	Cutting Depth	Light, Normal, Deep

The membership function for the thickness of the glove is constructed from three basic triangular membership functions. The thickness of the glove is measured in a thousandth of an inch (mil). Based on the thickness of the measured sample, a combined input membership function is plotted and shown in Fig. 13. The crisp input based on the membership function is defined as in equation (3).

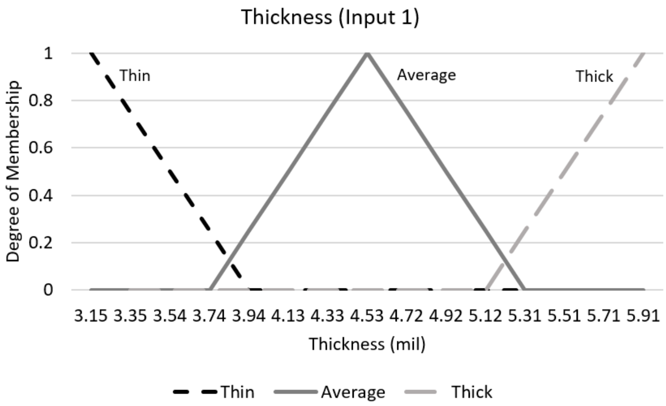

Fig. 13. Input Membership Function of Thickness Parameter

$$\mu_{i1}(x)\begin{cases} 0, & x_1 < 3.94 \\ \dfrac{x_1 - 3.94}{0.59}, & 3.94 \le x_1 \le 4.53 \\ \dfrac{5.12 - x_1}{0.59}, & 4.53 \le x_1 \le 5.12 \\ 0, & 5.12 \le x_1 \end{cases} \qquad (3)$$

x_1 represents the measured thickness of the glove, which is the first crisp input for the FCLG. The second input is the hardness of the template and the membership function is constructed from three primary triangular membership functions as well. The hardness of the cutting template material is measured by using the Rockwell Hardness Test method. Based on the measured value, a combined input membership function is plotted and shown in Fig. 14 and the corresponding crisp input is defined as in equation (4).

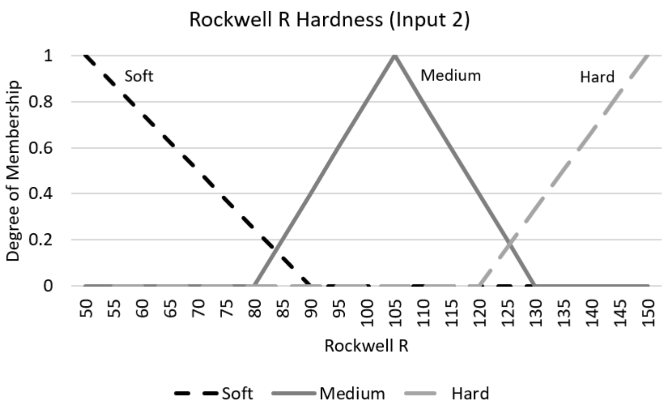

Fig. 14. Input Membership Function of Template Hardness

$$\mu_{i2}(x)\begin{cases} 0, & x_2 < 90 \\ \dfrac{x_2 - 90}{15}, & 90 \le x_2 \le 105 \\ \dfrac{120 - x_2}{15}, & 105 \le x_2 \le 120 \\ 0, & 120 \le x_2 \end{cases} \quad (4)$$

The output of the fuzzy logic system is the cutting depth. The cutting depth is the z-axis distance between the home position and the cut position of the latex glove cutting machine. The maximum cutting depth for the cutter is 75 mm and the minimum cutting depth for the cutter is 82 mm. Cutting depth of more than 82 mm would result in the cutter fracture or slip-ups. The simulated cutting depth results is plotted based on triangular membership function. The combined output membership function is shown in Fig. 15.

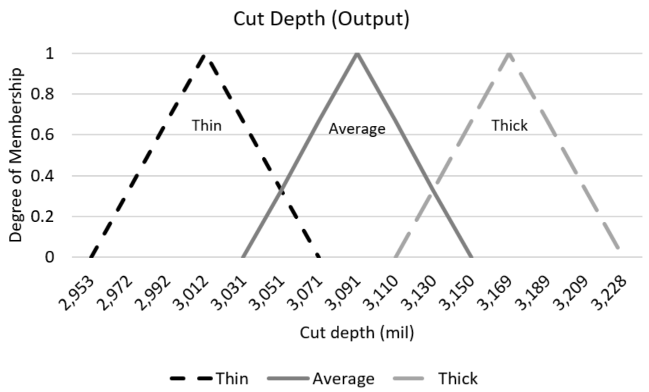

Fig. 15. Output Membership Function of the Cutting Depth

After constructing the membership functions for all the inputs and output, the knowledge base rules are created. A matrix of the thickness of the glove versus the hardness of the cutting template is constructed to determine the desire cutting depth for each possible case. A set of rules is built based on the matrix in the form of IF-THEN structures. In general, the general form of the rules is formed by the linguistic variables expressed in (5) [33], [34].

$$\text{IF } x_1 \text{ is } A_1 \text{ and } x_2 \text{ is } A_2 \text{ and } \ldots \text{ and } x_n \text{ is } A_n$$
$$\text{THEN } y_1 \text{ is } B_1 \text{and } y_2 \text{ is } B_2 \text{ and } \ldots \text{ and } y_m \text{ is } B_m \quad (5)$$

Where x_1 and x_2 are the inputs linguistic variable taking the linguistic value of A_1 and A_2, respectively. y_i is the output linguistic variable taking the linguistic value B_i [35], [36]. Once the rules are determined, the codes are written on the firmware of the latex glove samples cutting system to perform fuzzy logic based on inputs from the user. The fuzzy rules table used for the system is shown in Table II.

TABLE II
FUZZY RULES TABLE

		Thickness of Glove		
		Thin	Average	Thick
Hardness of the Template	Soft	Light	Normal	Normal
	Medium	Normal	Normal	Deep
	Hard	Normal	Deep	Deep

Based on inputs and output in Table II, the linguistic variables for each parameter is used to form the fuzzy rule for FCLG. The list of fuzzy rules is shown below.

1) If (THICKNESS is THIN) and (HARDNESS is SOFT) then (CUT-DEPTH is LIGHT)
2) If (THICKNESS is AVERAGE) and (HARDNESS is SOFT) then (CUT-DEPTH is NORMAL)
3) If (THICKNESS is THICK) and (HARDNESS is SOFT) then (CUT-DEPTH is NORMAL)
4) If (THICKNESS is THIN) and (HARDNESS is MEDIUM) then (CUT-DEPTH is NORMAL)
5) If (THICKNESS is AVERAGE) and (HARDNESS is MEDIUM) then (CUT-DEPTH is NORMAL)
6) If (THICKNESS is THICK) and (HARDNESS is MEDIUM) then (CUT-DEPTH is DEEP)
7) If (THICKNESS is THIN) and (HARDNESS is HARD) then (CUT-DEPTH is NORMAL)
8) If (THICKNESS is AVERAGE) and (HARDNESS is HARD) then (CUT-DEPTH is DEEP)
9) If (THICKNESS is THICK) and (HARDNESS is HARD) then (CUT-DEPTH is DEEP)

IV. Result and Discussion

A. System Performance without Fuzzy Logic

A cutting test is carried out to determine the conditions for the cutter to cut the samples completely. Before applying the fuzzy logic system, the cutting depth parameters are fixed without considering the thickness of the glove and hardness of the template. The thickness of powdered and non-powdered glove is measured and shown in Table III.

TABLE III
SPECIFICATION OF GLOVES FOR THE CUTTING TEST

Powdered Glove	Thickness (mil)	Non-powdered Glove	Thickness (mil)
A	3.94	G	4.53
B	4.73	H	5.50
C	5.51	I	4.52
D	3.93	J	5.52
E	4.75	K	5.51
F	5.52	L	6.29

In this work, three different templates are used. They are polyvinyl chloride (PVC) board, magnetic sheet, and transparent cover sheet. The thickness of the glove is measured as input for the fuzzy system. Table IV, Table V, and Table VI show the cutting results for the PVC board, magnetic sheet, and transparent cover sheet respectively. The cutting is performed without implementing the fuzzy logic control.

TABLE IV
CUTTING TEST (PVC BOARD) WITHOUT FUZZY SYSTEM

Glove	Sample							Number of samples cut
	1	2	3	4	5	6	7	
A	√	√	×	×	×	√	×	3
B	×	×	√	×	×	√	×	2
C	×	×	√	×	×	√	√	3
D	×	×	×	×	×	×	√	1
E		×	√	×	×	×	×	1
F	√	√	×	×	×	×	×	2
G	×	×	×	×	×	√	√	2
H	√	√	√	×	×	×	√	4
I	×	×	√	×	×	√	√	3
J	√	√	×	×	×	×	√	3
K	√	√	√	×	×	×	√	4
L	×	×	√	×	×	√	√	3

√: Complete cut ×: Incomplete cut

TABLE V
CUTTING TEST (MAGNETIC SHEET) WITHOUT FUZZY SYSTEM

Glove	Sample 1	2	3	4	5	6	7	Number of samples cut
A	√	√	×	√	√	√	×	5
B	×	×	√	√	√	√	×	4
C	√	×	×	√	×	×	√	3
D	√	×	×	×	√	×	√	2
E	×	√	√	×	×	×	×	2
F	×	√	√	×	√	×	×	3
G	×	×	√	√	√	×	√	4
H	×	√	√	×	√	×	√	4
I	×	√	√	×	√	×	×	3
J	√	×	×	√	×	×	√	3
K	√	√	×	√	×	√	√	5
L	×	×	√	√	√	×	√	4

√: Complete cut ×: Incomplete cut

TABLE VI
CUTTING TEST (TRANSPARENT COVER SHEET) WITHOUT FUZZY SYSTEM

Glove	Sample 1	2	3	4	5	6	7	Number of samples cut
A	√	√	√	√	√	√	×	6
B	√	√	√	√	√	√	×	6
C	√	×	√	√	√	×	×	4
D	√	×	×	×	√	√	√	3
E	×	√	√	×	×	×	×	2
F	×	×	×	×	×	×	×	0
G	√	√	√	√	√	√	×	6
H	×	√	√	×	×	×	×	2
I	√	×	√	√	√	×	×	4
J	√	√	√	√	√	√	×	6
K	√	×	×	×	√	√	√	4
L	√	√	√	√	√	√	×	6

√: Complete cut ×: Incomplete cut

Most of the samples are not cut through completely with the fixed cutting depth. However, there are more complete cut samples by using the magnetic sheet and transparent cover sheet as compared to the PVC board. It is found that the hardness of the PVC board is much higher compared to both the magnetic sheet and the transparent cover sheet. The PVC board has a Rockwell R hardness of 115. The magnetic sheet is made of polypropylene, which has a Rockwell R hardness of 92, while the transparent cover sheet is made of polyurethane, where the Rockwell R hardness is around 70. As the cutting depth parameter is fixed for all three cases, the cutting depth level is not adequate for the PVC board. Hence, the fuzzy logic system can help in determining the desired cutting depth parameter given different conditions. The example of an incomplete sample cut when using the PVC board as the cutting template is shown in Fig. 16.

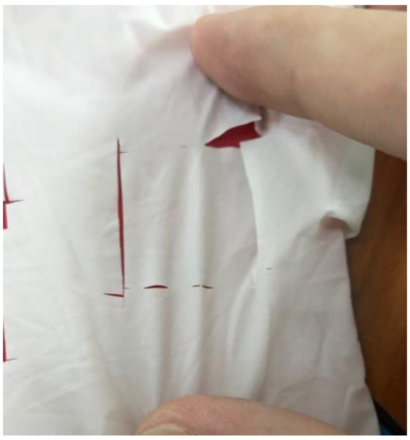

Fig. 16. Incomplete sample cut by using PVC board as the template

B. System Performance with Fuzzy Controller for Latex Glove (FCLG)

The inference engine in the microcontroller will decide which rule to apply based on the inputs provided by the user. After receiving fuzzy sets from the fuzzifier, it will convert the fuzzy sets for the defuzzifier to perform defuzzification. The defuzzifier will convert the fuzzy sets into crisp value as the output. When the user key in the specific thickness and hardness, the system will automatically operate and determine the desire cutting depth. In order to increase the accuracy of the cutting process, different gloves and templates are used in the test. The defuzzified crisp output which is the cutting depth base on the different glove and template is shown as Table VII.

TABLE VII
CUTTING DEPTH DETERMINED BY FUZZY LOGIC

Glove	Thickness (mil)	PVC board (mil)	Magnetic sheet (mil)	Transparent cover sheet (mil)
A	3.94	3130	3090	3039
B	4.73	3130	3130	3090
C	5.51	3169	3169	3129
D	3.93	3129	3090	3038
E	4.75	3110	3132	3091
F	5.52	3170	3170	3130
G	4.73	3130	3130	3090
H	5.50	3169	3169	3129
I	4.72	3130	3129	3090
J	5.52	3170	3170	3130
K	5.51	3169	3169	3130
L	6.29	3181	3180	3145

The results of the cutting test using the PVC board, magnetic sheet, and transparent cover sheet as the template is shown in Table VIII, Table IX, and Table X, respectively.

TABLE VIII
CUTTING TEST (PVC BOARD) WITH FUZZY SYSTEM

Glove	Sample 1	2	3	4	5	6	7	Number of samples cut
A	√	√	√	√	√	√	×	6
B	√	√	√	√	√	√	√	7
C	√	√	√	√	√	√	√	7
D	×	√	×	×	×	√	√	3
E	×	√	√	√	×	×	√	4
F	×	√	√	×	×	√	√	4
G	√	√	√	√	√	√	√	7
H	√	√	√	√	√	√	√	7
I	√	√	√	√	√	√	√	7
J	√	√	√	√	√	√	√	7
K	√	√	√	√	√	√	√	7
L	√	√	√	√	√	√	√	7

√: Complete cut ×: Incomplete cut

TABLE IX
CUTTING TEST (MAGNETIC SHEET) WITH FUZZY SYSTEM

Glove	Sample 1	2	3	4	5	6	7	Number of samples cut
A	√	√	√	√	×	√	√	6
B	√	√	√	√	√	√	√	7
C	√	√	√	√	√	√	√	7
D	×	√	√	√	√	√	√	6
E	×	√	√	√	√	√	√	6
F	×	√	√	√	√	√	√	6
G	×	√	√	√	√	√	√	6
H	√	√	√	√	√	√	√	7
I	√	√	√	√	√	√	√	7
J	√	√	√	√	√	√	√	7
K	√	√	√	√	√	√	√	7
L	×	√	√	√	√	√	√	6

√: Complete cut ×: Incomplete cut

TABLE X
CUTTING TEST (TRANSPARENT COVER SHEET) WITH FUZZY SYSTEM

Glove	Sample 1	2	3	4	5	6	7	Number of samples cut
A	√	√	√	√	√	√	√	7
B	√	×	√	√	√	√	×	5
C	√	√	√	√	√	√	√	7
D	×	√	√	√	√	√	√	6
E	×	√	√	√	√	×	×	4
F	√	√	×	√	√	√	√	6
G	×	√	√	√	√	√	√	6
H	√	√	√	√	√	√	√	7
I	√	√	√	√	√	√	√	7
J	√	√	√	√	√	√	√	7
K	√	√	√	√	√	√	√	7
L	√	√	√	√	√	√	√	7

√: Complete cut ×: Incomplete cut

The results for the magnetic sheet are the best as compared to the PVC board and the transparent cover sheet. It has a more stable and successful result for sample cutting with the aids of FCLG compared to the latex glove samples cutting system without a fuzzy logic controller. The result indicated that the system can cut through completely when the template surface is relatively soft. This is important to allow the blade to be pressed deeper into the template, as shown in Fig. 17.

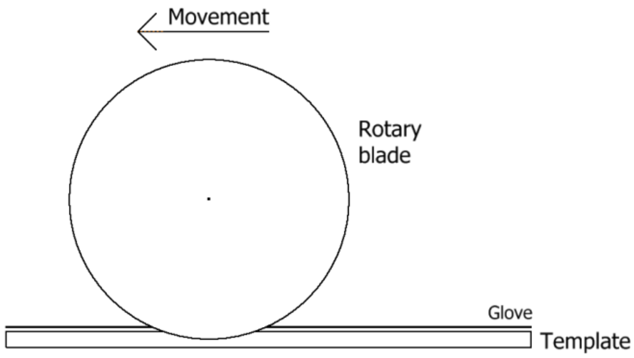

Fig. 17. Illustrate Diagram of the Cutting Process

The input parameters, the thickness of glove and the hardness of the cutting template of the FCLG is plotted, and a fuzzy output surface is generated. The output or the cutting depth fuzzy surface of the fuzzy logic controller is plotted and shown in Fig. 18.

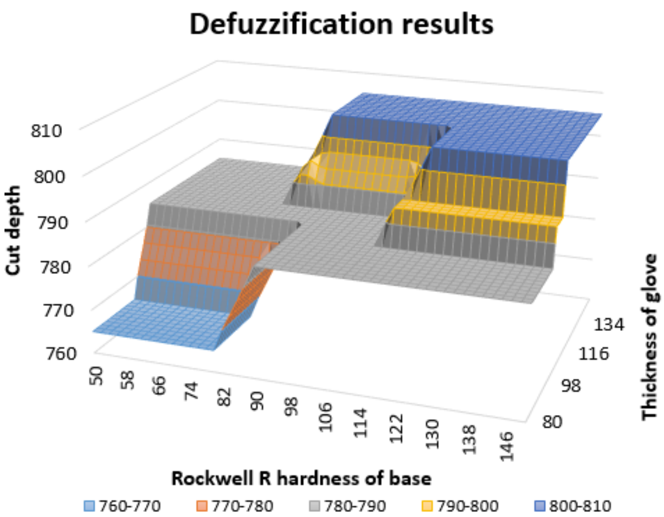

Fig. 18. Output surface of the fuzzy logic system

From Fig. 18, the results are matched with the rules provided. When the glove is thin, and the template is soft, the cutting depth is low. As the thickness of gloves and hardness of the template increase, the cutting depth needs to be increased too. In summary, the FCLG is successfully implemented on the latex glove samples cutting system.

C. Accuracy Test

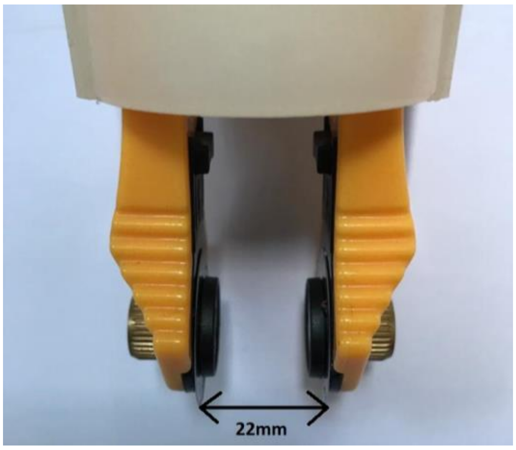

Fig. 19. Blade Distance between Two Rotary Cutters

Fig. 20. Sample Size Measurement

The FCLG performance is tested with six brands of the latex glove and seven pieces of samples are obtained from each glove. Three templates with different hardness are used and each test is performed four times for the results. A table is presented in Table XI to show the test arrangements.

TABLE XI
GLOVE BRAND AND SAMPLES TEST LIST

Brand	Glove Samples (Pieces)	Type of Template	Attempt
A	7	3	4
B	7	3	4
C	7	3	4
D	7	3	4
E	7	3	4
F	7	3	4
G	7	3	4
H	7	3	4
I	7	3	4
J	7	3	4
K	7	3	4
L	7	3	4
		Total Test Data	1008

Thus, a total of 1008 tests are performed for the latex glove fuzzy system. The test results with powdered globe and non-powdered glove; with and without FCLG are compared.

1) Accuracy Test on Powdered Glove

Table XII shows the cutting accuracy without the implementation of fuzzy logic. While the second, third and fourth sets of the accuracy tests are performed with the implementation of FCLG. The cutting accuracy test results are shown in Table XIII, Table XIV and Table XV.

TABLE XII
FIRST ATTEMPT: CUTTING ACCURACY ON POWDERED GLOVE WITHOUT FUZZY SYSTEM

Samples	Templates		
	PVC Board	Magnetic Sheet	Transparent Sheet Cover
Glove A	43.79%	95.60%	91.29%
Glove B	30.46%	92.56%	90.71%
Glove C	45.32%	93.94%	58.57%
Glove D	14.82%	94.83%	60.14%
Glove E	14.93%	94.50%	29.29%
Glove F	30.11%	94.58%	0.00%
Average	29.90%	94.34%	55.00%

TABLE XIII
SECOND ATTEMPT: CUTTING ACCURACY ON POWDERED GLOVE WITH FUZZY SYSTEM

Samples	Templates		
	PVC Board	Magnetic Sheet	Transparent Sheet Cover
Glove A	44.89%	60.14%	75.79%
Glove B	45.36%	59.96%	44.25%
Glove C	73.54%	75.14%	44.86%
Glove D	29.68%	29.71%	44.43%
Glove E	30.29%	30.04%	14.93%
Glove F	15.25%	45.21%	59.43%
Average	39.83%	50.04%	47.28%

TABLE XIV
THIRD ATTEMPT: CUTTING ACCURACY ON POWDERED GLOVE WITH FUZZY SYSTEM

Samples	Templates		
	PVC Board	Magnetic Sheet	Transparent Sheet Cover
Glove A	89.71%	44.93%	88.21%
Glove B	95.57%	60.11%	59.32%
Glove C	94.61%	88.93%	75.89%
Glove D	59.89%	60.04%	58.64%
Glove E	45.21%	59.93%	45.86%
Glove F	44.96%	59.21%	60.46%
Average	71.66%	62.19%	64.73%

TABLE XV
FOURTH ATTEMPT: CUTTING ACCURACY ON POWDERED GLOVE WITH FUZZY SYSTEM

Samples	Templates		
	PVC Board	Magnetic Sheet	Transparent Sheet Cover
Glove A	88.89%	90.71%	92.75%
Glove B	96.21%	95.14%	75.25%
Glove C	94.71%	93.93%	94.75%
Glove D	45.00%	87.96%	89.75%
Glove E	59.46%	89.11%	59.29%
Glove F	60.32%	89.89%	90.46%
Accuracy	74.10%	91.12%	83.71%

From the four sets of results, it is found that the magnetic sheet as a cutting template has the highest accuracy on the fourth test set while testing on powdered glove. It achieved 91.12% as compare to 74.10% accuracy by using PVC Board as the cutting template and 83.71% accuracy by using Transparent Sheet Cover as the cutting template.

2) Accuracy Test on Non-Powdered Glove

Second, for the non-powdered glove. Table XVI shows the cutting accuracy without the implementation of fuzzy logic. While the second, third and fourth sets of the accuracy tests are performed with the implementation of FCLG. The cutting accuracy test results are shown in Table XVII, Table XVIII and Table XIX.

TABLE XVI
FIRST ATTEMPT: CUTTING ACCURACY ON NON-POWDERED GLOVE WITHOUT FUZZY SYSTEM

Samples	Templates		
	PVC Board	Magnetic Sheet	Transparent Sheet Cover
Glove G	72.54%	96.36%	29.99%
Glove H	58.94%	95.58%	59.04%
Glove I	37.34%	96.61%	58.44%
Glove J	44.44%	95.70%	44.55%
Glove K	30.46%	98.48%	43.19%
Glove L	44.65%	94.80%	59.78%
Average	48.06%	96.26%	49.17%

TABLE XVII
SECOND ATTEMPT: CUTTING ACCURACY ON NON-POWDERED GLOVE WITH FUZZY SYSTEM

Samples	Templates		
	PVC Board	Magnetic Sheet	Transparent Sheet Cover
Glove G	89.71%	44.93%	88.21%
Glove H	95.57%	60.11%	59.32%
Glove I	94.61%	88.93%	75.89%
Glove J	59.89%	60.04%	58.64%
Glove K	45.21%	59.93%	45.86%
Glove L	44.96%	59.21%	60.46%
Average	71.66%	62.19%	64.73%

TABLE XVIII
THIRD ATTEMPT: CUTTING ACCURACY ON NON-POWDERED GLOVE WITH FUZZY SYSTEM

Samples	Templates		
	PVC Board	Magnetic Sheet	Transparent Sheet Cover
Glove A	58.98%	74.88%	89.09%
Glove B	74.55%	89.39%	75.11%
Glove C	59.05%	59.90%	74.51%
Glove D	45.20%	74.88%	73.15%
Glove E	73.83%	59.18%	75.17%
Glove F	73.85%	74.30%	87.63%
Average	64.24%	72.09%	79.11%

TABLE XIX
FOURTH ATTEMPT: CUTTING ACCURACY ON NON-POWDERED GLOVE WITH FUZZY SYSTEM

Samples	Templates		
	PVC Board	Magnetic Sheet	Transparent Sheet Cover
Glove A	95.61%	95.03%	95.92%
Glove B	96.17%	96.34%	94.44%
Glove C	95.02%	95.33%	96.54%
Glove D	95.98%	93.95%	89.11%
Glove E	85.92%	93.57%	95.23%
Glove F	45.00%	96.31%	94.75%
Accuracy	85.62%	95.09%	94.33%

From the four sets of results, it is found that the magnetic sheet as a cutting template has the highest accuracy on the fourth test set while testing on non-powdered glove. It achieved 95.09%% as compare to 85.62% accuracy by using PVC Board as the cutting template and 94.33% accuracy by using Transparent Sheet Cover as the cutting template.

Therefore, the magnetic sheet is suitable for glove cutting and this FCLG system can improve the cutting process by achieve higher accuracy compared to other materials as the cutting template.

D. Cutting Success Rate

This experiment is to determine the cutting completion of the sample. In order to cut a sample out of the glove, four sides of the square sample must be cut. The cutting completion is defined as the cutting success rate for the system. As similar to the accuracy test, a total of 504 tests are performed. The platform after the cutting test is performed shown as Fig. 21.

Fig. 21. Sample glove after Cutting Test are performed

1) Cutting Success Rate on Powdered Glove

The cutting results for powdered glove are compared between the latex glove samples cutting system with and without the FCLG. The results without the implementation of the fuzzy logic is shown in Table XX. While the second, third and fourth sets of test results (with implemented FCLG) are shown in Table XXI, Table XXII and Table XXIII, respectively.

TABLE XX
FIRST ATTEMPT: SUCCESS RATE ON POWDERED GLOVE WITHOUT FUZZY SYSTEM

Samples	Templates		
	PVC Board	Magnetic Sheet	Transparent Sheet Cover
Glove A	42.86%	71.43%	85.71%
Glove B	28.57%	57.14%	85.71%
Glove C	42.86%	42.86%	57.14%
Glove D	14.29%	42.86%	57.14%
Glove E	14.29%	28.57%	28.57%
Glove F	28.57%	42.86%	0.00%
Success Rate	28.57%	47.62%	52.38%

TABLE XXI
SECOND ATTEMPT: SUCCESS RATE ON POWDERED GLOVE WITH FUZZY SYSTEM

Samples	Templates		
	PVC Board	Magnetic Sheet	Transparent Sheet Cover
Glove A	42.86%	57.14%	71.43%
Glove B	42.86%	57.14%	42.86%
Glove C	71.43%	71.43%	42.86%
Glove D	28.57%	28.57%	42.86%
Glove E	28.57%	28.57%	14.29%
Glove F	14.29%	42.86%	57.14%
Success Rate	38.10%	47.62%	45.24%

TABLE XXII
THIRD ATTEMPT: SUCCESS RATE ON POWDERED GLOVE WITH FUZZY SYSTEM

Samples	Templates		
	PVC Board	Magnetic Sheet	Transparent Sheet Cover
Glove A	85.71%	42.86%	85.71%
Glove B	100.00%	57.14%	42.86%
Glove C	100.00%	85.71%	71.43%
Glove D	57.14%	57.14%	57.14%
Glove E	42.86%	57.14%	42.86%
Glove F	42.86%	57.14%	57.14%
Success Rate	71.43%	59.52%	59.52%

TABLE XXIII
FOURTH ATTEMPT: SUCCESS RATE ON POWDERED GLOVE WITH FUZZY SYSTEM

Samples	Templates		
	PVC Board	Magnetic Sheet	Transparent Sheet Cover
Glove A	85.71%	85.71%	100.00%
Glove B	100.00%	100.00%	71.43%
Glove C	100.00%	100.00%	100.00%
Glove D	42.86%	85.71%	85.71%
Glove E	57.14%	85.71%	57.14%
Glove F	57.14%	85.71%	85.71%
Success Rate	73.81%	90.48%	83.33%

By comparing the powdered glove test results, it is show that the latex glove samples cutting system with FCLG has improved with a success rate of 90.48% by using the magnetic sheet as the cutting template.

2) Cutting Success Rate on Non-Powdered Glove

Similar to the powdered glove cutting test, the cutting results for non-powder glove are compared between the latex glove samples cutting system with and without the FCLG. The results without the implementation of the fuzzy logic is shown in Table XXIV. While the second, third and fourth sets of test results (with implemented FCLG) are shown in Table XXV, Table XXVI and Table XXVII, respectively.

TABLE XXIV
FIRST ATTEMPT: SUCCESS RATE ON NON-POWDERED GLOVE WITHOUT FUZZY SYSTEM

Samples	Templates		
	PVC Board	Magnetic Sheet	Transparent Sheet Cover
Glove A	63.00%	50.00%	88.00%
Glove B	38.00%	44.00%	50.00%
Glove C	50.00%	50.00%	63.00%
Glove D	25.00%	50.00%	44.00%
Glove E	25.00%	63.00%	50.00%
Glove F	38.00%	69.00%	44.00%
Success Rate	39.83%	54.33%	56.50%

TABLE XXV
SECOND ATTEMPT: SUCCESS RATE ON NON-POWDERED GLOVE WITH FUZZY SYSTEM

Samples	Templates		
	PVC Board	Magnetic Sheet	Transparent Sheet Cover
Glove A	92.86%	92.86%	71.43%
Glove B	92.86%	85.71%	85.71%
Glove C	85.71%	92.86%	78.57%
Glove D	50.00%	85.71%	92.86%
Glove E	85.71%	85.71%	92.86%
Glove F	64.29%	92.86%	85.71%
Success Rate	78.57%	89.29%	84.52%

TABLE XXVI
THIRD ATTEMPT: SUCCESS RATE ON NON-POWDERED GLOVE WITH FUZZY SYSTEM

Samples	Templates		
	PVC Board	Magnetic Sheet	Transparent Sheet Cover
Glove A	85.71%	100.00%	71.43%
Glove B	100.00%	100.00%	85.71%
Glove C	85.71%	100.00%	92.86%
Glove D	85.71%	100.00%	78.57%
Glove E	85.71%	71.43%	78.57%
Glove F	85.71%	71.43%	92.86%
Success Rate	88.10%	90.48%	83.33%

TABLE XXVII
FOURTH ATTEMPT: SUCCESS RATE ON NON-POWDERED GLOVE WITH FUZZY SYSTEM

Samples	Templates		
	PVC Board	Magnetic Sheet	Transparent Sheet Cover
Glove A	85.71%	100.00%	85.71%
Glove B	100.00%	92.86%	100.00%
Glove C	100.00%	100.00%	100.00%
Glove D	100.00%	100.00%	100.00%
Glove E	100.00%	100.00%	100.00%
Glove F	85.71%	100.00%	100.00%
Success Rate	95.24%	98.81%	97.62%

By comparing the non-powdered glove test results, it is show that the latex glove samples cutting system with FCLG has improved with a success rate of 98.81% by using the magnetic sheet as the cutting template.

Based on the accuracy test and cutting success rate test, the total average performance of the system is calculated based on the latex glove samples cutting system with and without FCLG. The average system performance is shown in Table XXVIII.

TABLE XXVIII
AVERAGE SYSTEM PERFORMANCE OF CUTTING SYSTEM WITH AND WITHOUT FCLG

System Performance	Without FCLG		With FCLG	
	Powdered	Non-Powdered	Powdered	Non-Powdered
Accuracy	59.75%	64.50%	82.98%	91.68%
Success Rate	42.86%	50.22%	82.54%	97.22%

The performance of the system has significantly increased with the implementation of the FCLG. For powdered glove, the accuracy of the samples size has increased from 59.75% to 82.98%. While, the sample cutting success rate has increased from 42.86% to 82.54%. At the same time for the non-powdered glove, the accuracy of the samples size has increased from 64.50% to 91.68%. While, the sample cutting success rate has increased from 50.22% to 97.22%. Thus, the magnetic sheet and designed FCLG should be implemented and use for the latex glove sample cutting system.

E. Overall Equipment Effectiveness (OEE)

OEE is a simple method to determine the productivity and performance of a machine. Numerous advantages can be obtained such as reduce costs, increase efficiency and improve quality as long as the OEE is optimised. The OEE includes 3 main factors, which are availability, performance and quality. The three factor can be calculated using equation (5), equation (6) and equation (7) respectively.

$$Availability = \frac{Run\ time}{Planned\ production\ time} \tag{5}$$

$$Performance = \frac{Ideal\ cycle\ time \times Total\ count}{Run\ time} \tag{6}$$

$$Quality = \frac{Good\ count}{Total\ count} \tag{7}$$

Finally, the OEE takes into account of all losses happened and is calculated by using equation (8).

$$OEE = Avalability \times Performance \times Quality \times 100\% \tag{8}$$

In order to determine how FCLG increase the effectiveness, the OEE is calculated for all attempts of cutting test. Table XXIX and Table XXX shows the OEE for each attempt of cutting test on powdered glove and non-powdered glove respectively.

TABLE XXIX
OEE FOR FLCG CUTTING TEST (POWDERED GLOVE)

Attempt	Good Count	Quality	OEE
First	17	0.2698	27.0%
Second	19	0.3016	30.2%
Third	30	0.4762	47.6%
Fourth	41	0.6508	65.1%

TABLE XXX
OEE FOR FLCG CUTTING TEST (NON-POWDERED GLOVE)

Attempt	Good Count	Quality	OEE
First	34	0.5397	54.0%
Second	32	0.5079	50.8%
Third	45	0.7100	71.0%
Fourth	55	0.8730	87.3%

The OEE increases significantly from 54.0% to 87.3% for non-powdered glove while the OEE increases from 27% to 65.1% for powdered glove. The main problem in non-powdered glove is the size of the some samples did not reach the requirement. The possible reason why the samples cut did not fulfil the requirement is that the glove does not fit completely with the template and causes the uneven surface appeared. On the other hand, the OEE for cutting the powdered glove can be increases by cutting the samples with soft surface template only. It is because the incomplete cuts for powdered glove are mainly occur when PVC board is using as the template. However, the OEE might be decreases when the machine has operate for a longer period. The availability and performance will decrease as the frequency of breakdown and maintenance will increases at the future.

V. CONCLUSION

The latex glove cutting machine with the fuzzy logic controller is developed and implemented. With the implementation of the fuzzy logic, most of the glove samples are cut completely with proper cut depth parameter. The application of fuzzy logic has ensured that the cutting depth of the cutter is sufficient but not exceeding the limit. Besides, most of the cut samples have fulfilled the size requirement of dimension 2 cm by 2 cm. The overall OEE has increased significantly after applying the FCLG on the system. Hence, the developed FCLG is able to improve the overall system performance.

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