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Development of Man-Machine Interface Using Matlab: An Adaptive Network-Based Fuzzy Inference System Modeling For Laser Machining

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Abstract- **Development of GUI on MATLAB environment is rarely carried out by researchers especially for controlling complex and non-linear machining processes. Hence, it becomes more complicated and time consuming for one to explore artificial intelligent tools to model a process using MATLAB due to unfamiliarity and phobia of programming. In this paper, how GUI is developed and integrated to model laser machining process using Adaptive Network-based Fuzzy Inference System (ANFIS) together with GUI's ability in generating the model output is presented. Laser cutting machine is widely known for having the most number of controllable parameters among the advanced machine tools and it becomes more difficult for the process to be engineered into desired responses such as surface roughness and kerf width to achieve precision machining conditions. Knowing both laser processing and ANFIS programming are difficult and being fear of modelers, a novel GUI is developed and used as an interface to model laser processing using ANFIS with various setting capabilities where, numeric and graphical output can be printed. On the other hand, the GUI can also be used to predict the responses to conduct comparative analysis. To validate the accuracy of the ANFIS modeling, the error is calculated through Root Mean Square Error (RMSE) and Average Percentage Error. The RMSE values are compared with various type of trained variables and settings on ANFIS platform, so that the best ANFIS model can be finalized before prediction. The developed GUI can be used in industry of laser machining for an operator to optimize the best machine setting before the machine is operated. Thus, the industry could reduce the production cost and down time by off-hand setting as compared to the traditional way of trial and error method.**

I. INTRODUCTION

Laser cutting machine is one of new types of advanced machine tool that has been developed to improve machining process. However, when the machining process becomes more complex and difficult, the controllable parameters are proportionally increased to cater the need. This is where the computers replace human intuition when sensitive inputs need to be monitored and controlled by logical decision all the time. The result is the creation of artificial intelligence; fuzzy logic, neural networks and ANFIS to generate better decision over critical data. After years of development, MATLAB is now capable of doing programming job the same as C/C#, Visual Basic and Fortran or better. It can also be integrated with the functionality of other programs which makes MATLAB far more versatile than their predecessor. Since MATLAB is advanced software that can compute complex algorithm, most of the developed GUIs are designed to be simple and user friendly. [1] had developed Matlab based Graphical User Interface (GUI) to design the LQG controllers applicable to antennas and radio telescopes. The GUI was developed to simplify the design process and user-friendly to enable design of an LQG controller for one with a limited control engineering background. The user is asked to manipulate the GUI sliders and radio buttons to watch the antenna performance. MATLAB's GUI is also used for AI application such as neural network as studied by [2]. They proposed a system which can discriminate between amplitude modulation (AM), frequency modulation (FM), double sideband (DSB), upper sideband (USB), lower sideband (LSB) and continuous wave (CW) modulations. A new fuzzy rule acquisition method for tool wear estimation using radial basis networks to find the optimal rules combination to compose fuzzy reasoning mechanism and options related to the membership functions (MFs) has been developed by [3]. On the other hand, CNC tool wear detection using neurofuzzy classification system has been conducted by [4]. The investigation uses three different types of membership function for ANFIS training and compared their differences of accuracy rate of the turning tool-state detection. [5] had developed ANFIS classification application for drill tool-failure detection, where, a fuzzy logic based decision mechanism was developed to determine tool wear condition using drilling forces.

In this paper, an ANFIS-LASER-GUI has been developed using MATLAB to model and control the critical input parameters of a CO_2 laser cutting machine, where the desired responses are surface roughness and kerf width.

Laser cutting machine is a very complex machine with respect to the influences of machining parameters, such as; cutting speed, duty cycle, frequency, power, focal distance, gas pressure, stand of distance, etc. The selection of machinability data has played an important role in the effectiveness of machine tool utilization which directly influences the overall product quality. The influence of the machining parameters on machine tools are not always precisely known and hence, it becomes difficult to recommend the optimum machinability data for machining process.

II. ANFIS-LASER GRAPHICAL USER INTERFACE DEVELOPMENT

ANFIS Model using neuro-adaptive learning techniques which are similar to those of neural networks was originally presented by Jang, [7]. Given an input/output data set, ANFIS constructs fuzzy inference system (FIS) whose membership function parameters are adjusted using back-propagation algorithm or other similar optimization techniques. [8] has used hybrid genetic and SVD methods to design ANFIS networks, where else [9] has applied ANFIS for the prediction of surface roughness in end milling. The use of ANFIS for inverse prediction of hole profiles was carried out by [10]. Development and customization of desired graphical user interfaces using MATLAB is possible and very much appreciated, where, users are no longer need to rely on programs such as C++ or visual basic to integrate machining processes and artificial intelligent tools. Since the purpose of GUI is to make the work handling easier and least complicated, the interface is represent by basic graphics such as button and pull down menu. Operators are only required to handle graphic objects while the program automates the work to be done. GUIDE (Graphic User Interface Developing Environment) is an application within MATLAB environment used to create the GUI. The application has the entire graphics interface which can be used to develop the interface and utilized by researchers of various disciplines.

III. LASER MACHINING

Laser beams are used extensively for a variety of material-removal applications because they provide highly concentrated energy sources that can be easily transmitted and manipulated. Micro-mechanical structures are becoming more common with the ever increasing demand for new micro-fabrication tools. As feature sizes become smaller and smaller, i.e. typically below 100 μm, conventional mechanical approaches to cutting, drilling and shaping materials may be replaced with photon or particle beam techniques that enable geometric features as small as laser wavelengths (smaller than a micrometer) to be created with a high degree of precision and repeatability. In addition, laser fabrication processes are non-contact, dry, and clean operations that enable ease of automation. The nonlinear behavior of the laser-material interactions plays a significant role in forming the final surface profile and the resultant geometry of the machined micro-features. The need to precisely control a large number of parameters, often with random components, makes the task of improving the process performance very difficult. Moreover, modeling all these factors using conventional, analytical and numerical methods poses a substantial challenge. In practice, the operator has to perform a number of experiments to set the appropriate process control parameters related to the laser apparatus, motion control system, and workpiece material. This trial-and-error approach is costly and time consuming especially for a small batch production or prototyping, and does not ensure near optimality with a given set of process conditions and manufacturing objectives. Laser cutting is used in precision industries as it has the ability to cut complex profiles featuring extra ordinary shapes, corners, slots, and holes with high degree of repeatability and small region of heat affected zone (HAZ). In laser machining, surface roughness is one of the most important quality evaluation factors besides kerf width. The surface roughness is generally dependent upon the properties of the work material being cut, workpiece thickness, focal length, stand of distance, gas pressure, cutting speed, etc. including the type of cutting gas. Besides the investigation of CO2 laser cutting parameters, investigations are also being studied to further understand the relationship between the gas and the cutting parameters to obtain highly précised cut quality.

IV. EXPERIMENTAL SETUP AND PROCEDURE

In this experiment, seven input parameters were controlled, namely; stand of distance, focal distance, gas pressure, power, cutting speed, frequency and duty cycle. A nozzle diameter of 0.5 mm was used with focused beam diameter of 0.25 mm. Material used in this experiment is grade B, Manganese-Molybdenum pressure vessel plate, with a nominal gauge thickness of 5.0 mm and Tensile Strength of 690 MPa. The plate was cut to the dimension about 1.2 meter length and 0.7 meter width. A cut length of 20mm performed over all the 128 profiles on the plate. Total of 128 experiments have been conducted based on the DOE matrix. All the experimental data sets and the objective functions have been incorporated into the developed ANFIS-GUI to optimize the conditions of both laser and ANFIS in developing a predictive model. A schematic view of laser machining experimental setup is shown in Fig. 2.

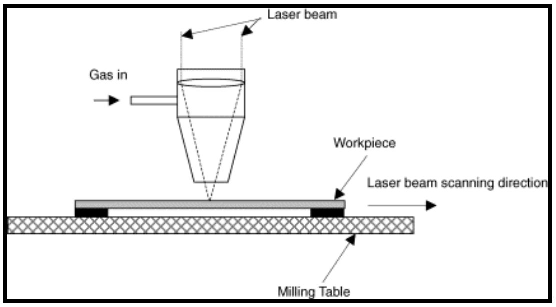

Fig 2: Schematic of laser machining

V. EXPERIMENTAL PARAMETERS, MACHINES AND EQUIPMENTS

Laser machine:

- Model: Helius Hybrid 2514 CO_2 Laser Cutting Machine
- Controller: FANUC Series 160 i-L
- Maximum capacity: 4 kW
- Laser source that use to create laser beam is CO_2 gas. The real ingredient is mixture of N_2 (55%), He (40%) & CO_2 (5%) with purity 99.995%.
- Pressure = Max 3 bar

Controllable parameters:

Variables	Level	
	Low	**High**
Power (Watt)	2500	2800
Cutting speed	800	1200
Frequency (Hz)	800	1000
S.O.D (mm)	1	1.5
F.D (mm)	0	1
Pressure (Bar)	0.7	1
Duty Cycle (%)	40	80

Surf tester:

- Mitutoyo Surftest SJ301
- Sampling length range (0.8 ~ 8)

Work Material:

- DIN 17155 HII standard
- 5mm Manganese-Molybdenum
- Grade: B
- Tensile Strength: 550-690 MPa

Data collection and interpretations:

- All the experimental materials, procedures, data collections, analysis, etc. are conducted as per the standard recommendations of 'Laser Cutting of Metallic Materials' German Standard, DIN 2310-5.

- The DIN EN ISO 9013:2000 is referred as it gives the terminological definitions and describes criteria for evaluating the quality of cutting surfaces, quality classifications and dimensional tolerances. It applies in the case of laser beam cuts from material thickness of between 0.5mm and 40mm.

VI. METHODOLOGY

The methodology for carrying out the project is represented in the form of a flow chart as illustrated in Fig. 3.

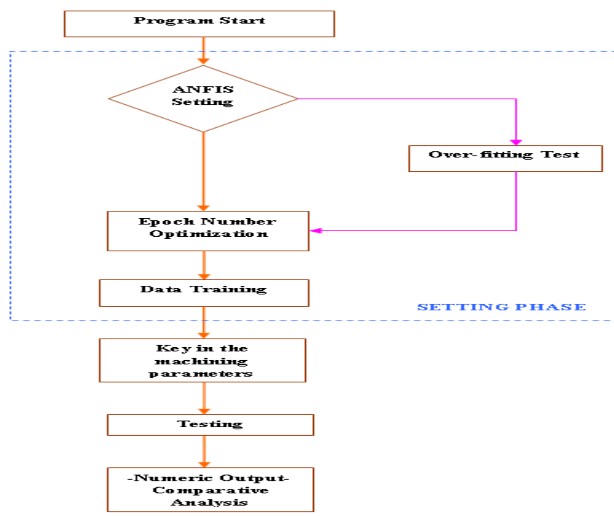

Fig. 3: Methodology used for ANFIS-LASER GUI development

The program could be started by clicking the executable file, later, click 'ANFIS Parameter' and select membership type together with its optimization method. If appropriate epoch number is unknown, set epoch number to 100 to test over- fitting, where this will provide optimized and best epoch number for the selected settings and model. Train the data by clicking 'Train' button and observe the RMSE and APE to the satisfactory level. Once done, finalize the model and key-in the laser machining parameters and click 'test' for numerical and graphical output together with its comparative analysis of observed vs. predicted.

VII. ANFIS-LASER INTERFACE PROGRAMMING

An ANFIS-GUI is created to help user to use artificial intelligence (AI) such as ANFIS (Adaptive Network-based

Fuzzy Inference System) to predict output. ANFIS can predict data using Sugeno FIS (Fuzzy Inference System) to relate membership and tune it using either back propagation or hybrid method. Seven input corresponding parameters namely; power, speed, pressure, focal distance, standoff distance, frequency, duty cycle with their respective two responses; surface roughness and kerf width were used for the ANFIS training. The ANFIS-GUI is programmed to train 2.5mm and 5.0mm material and predict their responses using the setting of the seven inputs. The ability of ANFIS to predict the data accurately is based on the setting used to train the data. Part of the coding as shown in Fig. 4 with the commands subjected for RMSE, epoch number, graphical output, etc. are used to integrate the laser data sets into ANFIS platform. Therefore, the developed GUI is linked to this syntax and command which works at the background to generate the output.

```
%% Create ANFIS from training data

% FIS is automatically generated based on the input and output data
in_fisra2 = genfis1(handles.trnData_ra2,2,mfType);

[out_fisra2,trn_error,stepsize,chkFis,chk_error] =
anfis(handles.trnData_ra2,in_fisra2,handles.epochnumber,1,handles.chkData_ra2
,opti_num);

%% RMSE check on the predicted data
predict = evalfis (handles.input_2,out_fisra2);
error = predict - handles.ra2' ;
mse_data = mse (error,predict);
rmse = sqrt (mse_data);
set (handles.rmse_display,'string',num2str(rmse));

%% Average Percentage Error on the predicted data
abs_error = abs (error);
abs_predict = abs (predict);
percent = (abs_error'./abs_predict');
avg_percent = mean (percent* 100);
set (handles.avg_display,'string',num2str(avg_percent));


% Figure of overfitting training will popup
    if handles.epochnumber == 100;
    [a, b] = min(chk_error);
    figure(1),plot(1:100, trn_error, 'g-', 1:100, chk_error, 'r-', b, a,
'ko');
    title('Training (green) and checking (red) error curve');
    xlabel('Epoch numbers');
    ylabel('RMS errors');

    end

% Plot for membership functions
figure (2),subplot(3,3,1), plotmf(in_fisra2, 'input', 1), xlabel('SOD');
subplot(3,3,2), plotmf(in_fisra2, 'input', 2), xlabel('FD');
subplot(3,3,3), plotmf(in_fisra2, 'input', 3), xlabel('Pg');
subplot(3,3,4), plotmf(in_fisra2, 'input', 4), xlabel('P');
subplot(3,3,5), plotmf(in_fisra2, 'input', 5), xlabel('Sc');
subplot(3,3,6), plotmf(in_fisra2, 'input', 6), xlabel('Freq');
subplot(3,3,7), plotmf(in_fisra2, 'input', 7), xlabel('Cd');
```

Fig. 4. Part of the programmed syntax used in integrating ANFIS- LASER-GUI

VIII. RESULT AND DISCUSSION

The developed ANFIS-LASER-GUI is the simplest user interface for modeling of laser processing using ANFIS. To date, there is no such GUI developed and this can be used by the end user of any field to understand the details of laser processing and its significant parameters.

The GUI as shown in Fig. 5 is the completed version of ANFIS-LASER-GUI which has been created using MATLAB environment to predicting surface roughness and kerf width of the work material Mn-Mo with thickness of 2.5mm and 5mm.

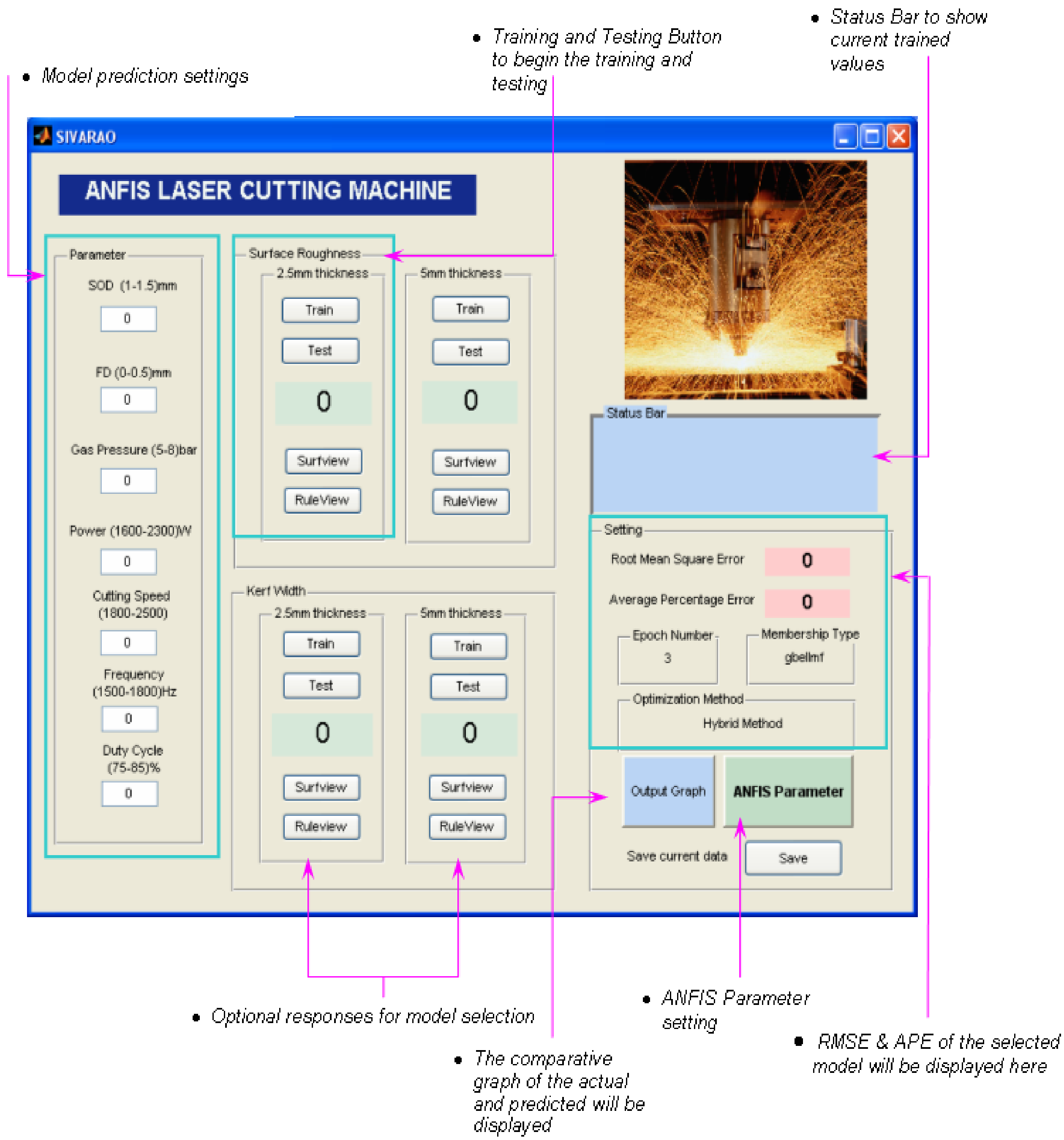

Fig. 5. Completed ANFIS-LASER graphical user interface for model development

The developed GUI functions to provide the fullest output of ANFIS capability by simple steps which can be done by almost anybody even without an engineering knowledge. The GUI can also be used to educate engineering personals to understand the fundamentals of ANFIS modeling and laser processing. Among the key features of the GUI output are; over-fitting, surface modeling, rule viewer, membership function and comparative scatter plot. These are the elements used to interpret the correlations among man, model and machine.

Over-fitting detection and optimization

The GUI is developed to detect over-fitting and to help user to select the appropriate number of epochs. Figure 6 shows the dialog-box to optimize the epoch number. The optimization can be done via various setting of optimization methods and membership functions.

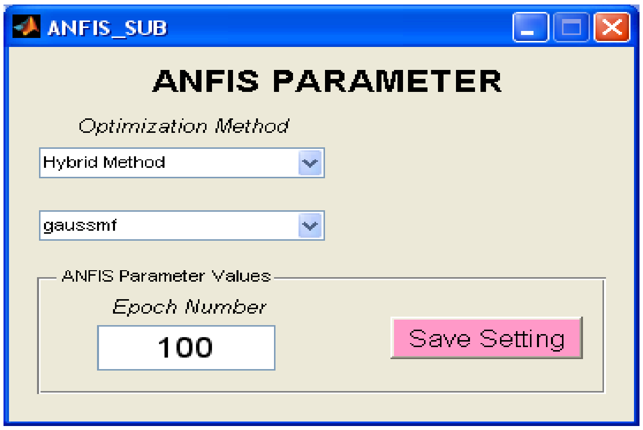

Fig. 6. Over-fitting test dialog-box

To enable the checking of over-fitting, simply set the number of epochs to 100 and a figure plotting the checking error and training error will popup indicating the optimized values for appropriate epoch number selection as shown in Fig. 7.

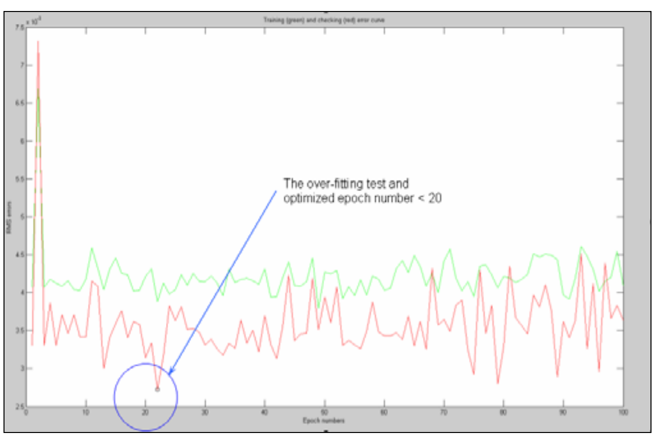

Fig. 7. Optimized epoch number prior to checking error and training error.

Surface Model

The surface viewer is a window where user can see the correlation of the input(s) to its response via ANFIS model. The output is presented by 3D surface model as shown in Fig. 8 (a) & (b).

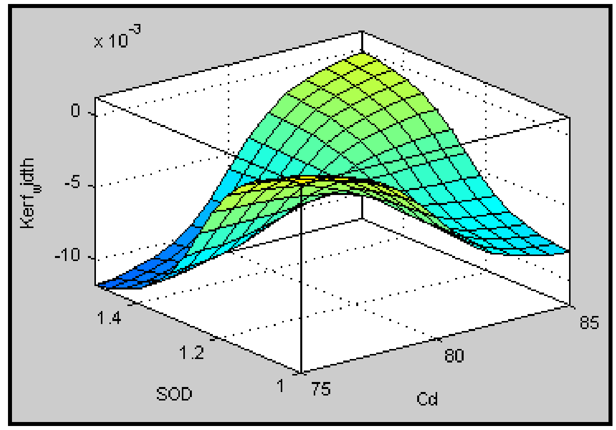

Fig.8 (a): Surface model of stand of distance and duty cycle for the response of kerf width

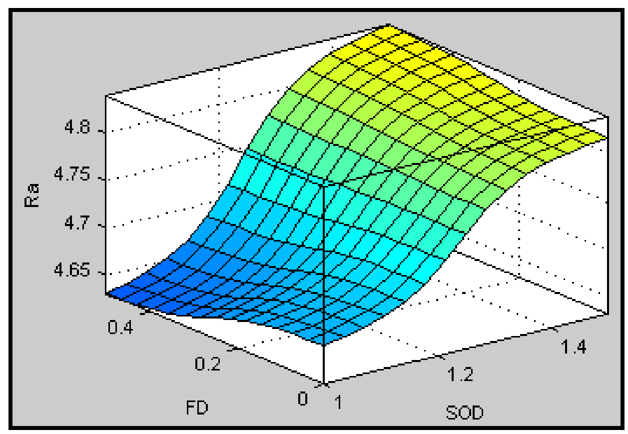

Fig.8 (b): Surface model of focal distance and stand of distance for the response of surface roughness

Rule Viewer

Rule viewer presents a sort of micro view of the fuzzy inference system, where the rule viewer displays a roadmap of the whole fuzzy inference process. It is bases the fuzzy inference diagram with a single window with plotted curve nested in it as shown in Fig. 9. The plotted curve across the top of the figure represent the antecedent and consequent of the first rule. Each rule is a row of plots, and each column is a variable. The rule numbers are displayed on the left of each row. The first seventh columns of plots show the membership functions referenced by the antecedent, or the if-part of each rule. The last plot in the seventh column of plots represents the aggregate weighted decision for the given inference system. This decision will depend on the input values for the system.

The defuzzified output is displayed as a bold vertical line on this plot. The variables and their current values are displayed on top of the columns. The Rule Viewer shows one calculation at a time and in great detail.

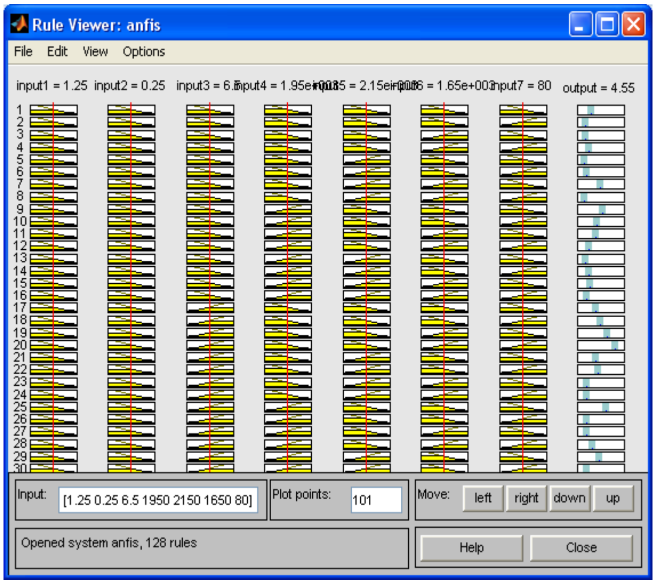

Fig. 9. The Rule viewer for the ANFIS-LASER tested model

Model Prediction

After the GUI is programmed and linked with the ANFIS command via callbacks and M-Files, the program is then tested for its ability to predict the machining accuracy towards achieving the estimated response. ANFIS setting was selected based on comparing RMSE values between different settings. The lowest RMSE indicates the best

Membership Functions

The membership functions for the trained model as shown in Fig. 10 with smooth curve interaction for each parameter indicates the best fit of the developed model.

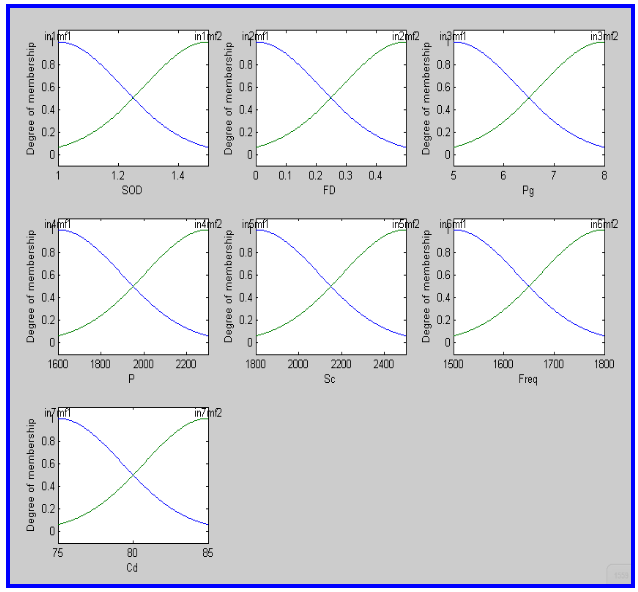

Fig. 10. Membership function of each parameter for the tested model

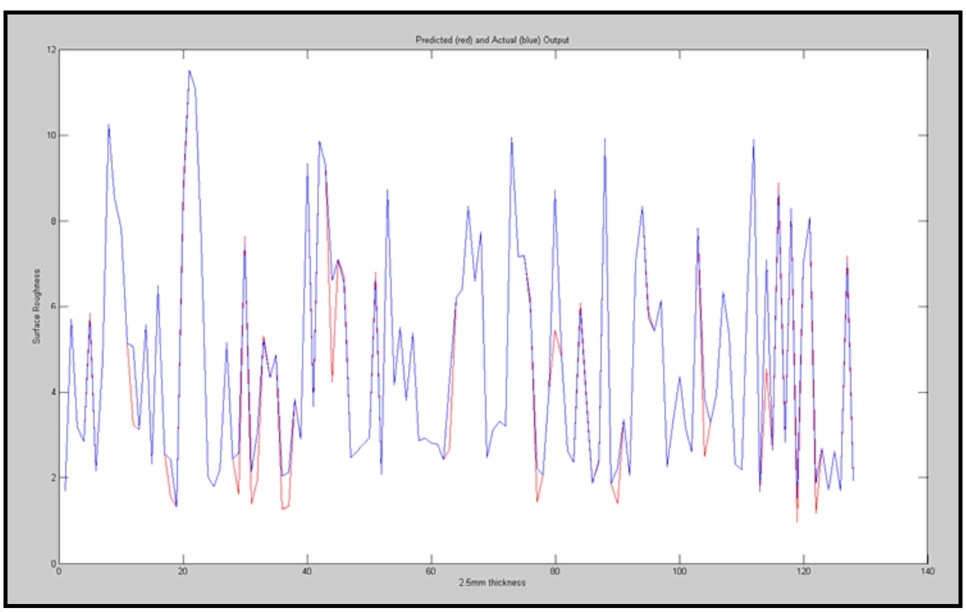

Fig. 11. ANFIS model predicted vs. observed for surface roughness

IX. CONCLUSION

The MATLAB based graphical user interface (GUI) has been successfully developed and tested for its ability for modeling the laser processing using Adaptive Network-based Fuzzy Inference System (ANFIS). It has been validated to be capable of testing the best setting of the intended model. This GUI enables a user even without the depth knowledge of programming and laser processing to develop a sound model by selecting significant variables on ANFIS platform. On top of that, the user can simply read the Root Mean Square Error (RMSE) and Average Percentage Error (APE) from the status bar to identify the model strength. GUI implementation on ANFIS is proved to be more efficient and ANFIS has shown the greatest prediction ability in modeling the complex and non-linear behavior of laser processing. The designed GUI is also user friendly and makes the entire steps of ANFIS modeling easier then ever. This ANFIS-LASER-GUI permits anybody for the matter to model laser machining with ANFIS for the responses of surface roughness and kerf width. This task is being further extended into the development of universal GUI using MATLAB environment which will be published in nearest future.

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