Comparative study on Mamdani-Type Fuzzy Inference Systems and Regression model for end milling process using AA 6082T6

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Abstract. The goal of this observes is to take a look at the effect of machining parameters on surface roughness in end milling. An incipient technique in modelling surface roughness that makes use of synthetic perspicacity implements is defined in this paper. This paper fixates on growing empirical models utilizing fuzzy logic and regression analysis. The values of surface roughness presaged with the aid of using those fashions are then in comparison. The effects confirmed that the proposed gadget can considerably boom the precision of the product profile whilst in comparison to the traditional approaches, like regression analysis. The effects designate that the regression modelling method may be effectively applied for the presage of surface roughness in dry machining.

Keywords: End milling, Examine, focus, fuzzy, dry

1. Introduction

Fuzzy common sense become first proposed and created with the aid of using Zadeh (1965) \([1]\) as a technique to decipher unsure statistics in a manner that seemed like human motive and phonetic systems greater closely than normal coherent frameworks. It consists of envisioned questioning to inspire demonstrating in human etymological phrases together with objectives that might be phonetically determined \([2]\). Then later on is visible as a questionable engineering agency for 2 decades, fuzzy motive needs at lengthy ultimate been recounted as a growing innovation because of the overdue 1980s. This could be typically due to a complete display from claiming powerful provisions going beginning with purchaser products, with mechanical method control, ought to automobile provisions \([3]\). Fuzzy motive can be nearer on soul ought to mankind's hypothesis moreover not unusual place dialect over habitual valid frameworks \([4]\). Fuzzy frameworks would exceptionally of service done two general contexts: (1) for particular circumstances directing, including profoundly unpredictable frameworks whose practices are not great understood, Furthermore (2) to particular circumstances the place an approximate, Yet fast, the result is warranted \([5]\). Traditional control hypothesis may be dependent upon those scientific models that portray those physical plants under attention. The substance of fuzzy control is to manufacture a model of mankind's master who is skilled in regulating the plant without supposing as far as a scientific model \([6]\).
Fuzzy logic could have been putting ahead soonest for 1965 via way of means of L.A. Zadeh. A standout among the ones basic provisions from claiming fuzzy common sense could have been the metro framework for Sendai town for Japan. That related impact confirmed that fuzzy logic manipulates could have been higher than common manipulate. In any case, locating loopy the one's proper lead located moreover identifying fuzzy variables is time expending fill in. For example, within side the relevant framework of Sendai, with getting proper input sets, the unique architects used some months. Similarly, to the focal ventilating framework area today, there's a lengthy method as a way to discern out a full-grown grasp fuzzy manipulate version which needs to require loads approximately mission background [7]. Ventilating perhaps now no longer first-rate An sake of the product, anyhow via way of means of using plans Furthermore techniques of ventilating with make solace What's extra normal residing nature's area identical time at identical the lengthy haul decrease the ones ravages approximately the manner and achieve a proper feeling settlement for human and nature to the maximum intense degree [8]. Nowadays, ventilating frameworks want resources in most cases observed clinched along with houses what’s extra offices, what’s extra, performed almost at open encased spaces. Whatever stays of the paper could be composed as takes after place II affords for the ones Contrast the center of Mamdani additionally Sugeno FIS. Segment III shows the development from claiming Mamdani FIS. Area IV shows the improvement of Sugeno-kind FIS. The place affords for consequences Also dialogs What's extra phase VI finishes. Many researchers have studied the consequences of diverse machining parameters at the aluminum alloy and investigated appropriate choicest parameters [9-12], more than one performance optimization inclusive of center line common roughness (Ra) and slicing force (Fz) the usage of Tops is and fuzzy common sense carried out via way of means of Tamiloli et al. (2016)[13] in end milling.

Surface irregularity and surface texture had been taken into consideration in Luis Perez [14]; Azouzi and Guillot [15]; Fuzzy common sense that's spotting and figuring out structures, has been evolved and used widely [16]. Sokovowski [17]; has proven many sensible programs of fuzzy common sense structures.Yesaswi et al [18] studied modeling and investigation of nano materials with CNC milling. A single response optimization using the Taguchi method was studied by Rajayalakshimi [19]. Analytical and empirical models have been developed using NN, Genetic algorithm, Taguchi, and response surface methodology to calculate output response for several materials like alloy and composites [16-18].

2. Materials and Method

The end milling process consider in this work AA6082T6 is discussed following sections.

2.1 Experimental procedure

The one-side tungsten carbide insert is carried out by the end milling operation. The AA 6082T6 rectangular block scale was 100 x 50 x 35 mm for the work piece considered for this work. Cutting procedure on a piece of work with a straight profile of the piece of work. Feed, velocity, and cutting depth are the input parameters considered. Feed ranges (20 mm/min, 40 mm/min, and 60 mm/min), cutting speed speeds (45 rpm, 65 rpm, and 85 rpm), and cutting depths (1 mm, 1.25, and 1.5 mm) are the dimensions considered. Based on the L9 orthogonal array experiments were conducted to measure the surface roughness with help of a surface roughness tester (SJ 210) for straight a measured and values are tabulated in table 1.

2.2 Fuzzy logic-based model

The important fuzzy common sense version at the same time as experimentally predicting the quit milling reducing parameter for AA6082T6 on surface roughness. In the built fuzzy version, 3
monitors, feed, rpm, and reduce the intensity of reducing enter parameters are taken into account. Figure 1 presents the enter/output block diagram of the designed fuzzy common sense version. The cause of the bushy common sense is to derive from the given enter/output records systematically.

![Figure 1. Structure of Fuzzy inference system](image)

## 3. MAMDANI-TYPE FIS

The Mamdani method may also usually be diagnosed to acquire grasp data. This allows one to explain the finesse in a greater perceptive, greater human-like mode. Mamdani-Type FIS, however, involves a beneficent load of computation. These bendy cam wood structures are used to redo the cap potential of involvement in any such manner that fuzzy shape higher fashions the knowledge. The enormous majority of the essential disparity among Mamdani-FIS is the course where in the bushy inputs produce the sparkling yield. At the equal time that the technique changed into utilized by Mamdani-Type FIS to call for fuzzification of a fuzzy output, using Sugeno-Type FIS weighted Normal with the sparkling yield figure. Those expressive powers will omit what's greater interpretable approximately Mamdani yield within side the Sugeno FIS because the effects of the standards do now no longer require fuzzy aid [23]. Anyway, due to the fact the weighted normal change the long-time period price defuzzification method, Sugeno calls for favored making plans chance. Mamdani-Type FIS may be usually used in the primary criterion of choice help because of the interpretable and everyday life of the principal basis. Different contrasts require help that calls for yield enrolment functionality for Mamdani FIS whilst no yield enrolment paintings are needed for Sugeno FIS. The final ANFIS machine can be coordinated to streamline the outputs.

### 3.1 EXPANSION OF MAMDANI-TYPE FIS

Mamdani Fuzzy version is used to enhance give-up milling. It includes 3 velocities, feed, and Doc inputs which have surface roughness. The device has one overall performance controlling the parameters of machining. The feed, pace, and reducing intensity need to be among 20 rpm and forty mm / min, among forty-five and eighty-five rpm, and among 0.5 and 1.5 mm for Doc. As visible in Figs.2 and three, every one of the inputs has 3 Gaussian functions. The overall performance, i.e. surface roughness is taken from 0.5 to 1.01, and Figure three suggests Nine Gaussian club functions. Figures 4 and 5 show the policies and the guideline of thumb editors for the milling process.
Figure 2. Mamdani fuzzy logic designers

Figure 3. Surface roughness Gaussian membership functions

Figure 4. Mamdani rule editor
Figure 5. Rule viewer of Mamdani FIS

4. Regression Equation

In making plans and undertaking the test, L9 orthogonal array. Selected elements of the test have been modified in 9 ranges of value. This approach lets in investigating the Minitab software and the expected mathematical version is extra reliable. The subsequent step was milled into to estimate the version. Experimental records have been placed into the version and surface roughness parameters have been calculated (see Table 1). The above empirical expression turned into installed primarily based totally on the regression evaluation for predicting surface roughness of dry end milling. After experimental data processing (Table 1) adequate regression model was obtained:

\[
SR = -0.22508 - 0.00015 \times \text{Feed} + 0.002217 \times \text{speed} + 0.6773 \times \text{doc}
\]

5. Results and Discussion

The plots obtained for the machining process method after simulating Mamdani-type FIS are shown in Figs. 3, 4, and 5. Figures 6, and 7 show the Mamdani 3D surface viewers of machining parameters and surface roughness relations.

Figure 6. Surface view of Mamdani-type FIS of Feed, speed, and SR
Figure 7. Surface view of Mamdani-type FIS of speed, Doc, and SR

Table 1. Comparisons of Experimental, Regression, and Mamdani values.

| A  | B  | C   | Experimental | Regression | Mamdani |
|----|----|-----|--------------|------------|---------|
| 20 | 45 | 1   | 0.514        | 0.549      | 0.544   |
| 20 | 65 | 1.25| 0.761        | 0.763      | 0.717   |
| 20 | 85 | 1.5 | 0.936        | 0.976      | 0.976   |
| 40 | 45 | 1.25| 0.742        | 0.715      | 0.831   |
| 40 | 65 | 1.5 | 0.928        | 0.929      | 0.974   |
| 40 | 85 | 1   | 0.763        | 0.635      | 0.700   |
| 60 | 45 | 1.5 | 0.933        | 0.882      | 0.957   |
| 60 | 65 | 1   | 0.504        | 0.587      | 0.549   |
| 60 | 85 | 1.25| 0.756        | 0.801      | 0.700   |

Table 2. Comparisons of statistical output values

| FIS          | Multiple R | $R^2$ | Adjusted $R^2$ | Standard Error |
|--------------|------------|-------|----------------|----------------|
| Mamdani      | 0.9307     | 0.8662| 0.7859         | 0.0766         |
| Regression   | 1          | 1     | 1              | 1.08077588E-16 |
| Experiment   | 0.9236     | 0.853 | 0.765          | 0.079          |
The results obtained indicate that Mamdani FIS and Sugeno FIS perform similarly for the end milling application in question. The only difference that has been found is that the Sugeno FIS end milling system runs at maximum capacity, while the Mamdani-type FIS does not run at full capability.

6. ANOVA

The most important element that drastically effecting the surface roughness is the depth of cut. ANOVA became performed to take a look at the impact of the end manner variables. The effects acquired from ANOVA are proven in Tables 3, 4, and 5. It was found from figure 9, that the feed with 40mm/min, 85rpm, and 1.50 mm depth of cut is can achieve the minimum value of surface roughness.

### Table 3. ANOVA for Experimental values

| Factor | SS        | Dof | MS    | % Contribution |
|--------|-----------|-----|-------|----------------|
| Feed   | 0.011912  | 2   | 0.006 | 5.53           |
| Speed  | 0.015491  | 2   | 0.0077| 7.19           |
| Doc    | 0.172243  | 2   | 0.0861| 79.92          |
| Error  | 0.004     | 2   | 0.002 | 7.37           |
| Total  | 0.21553   | 8   |       | 92.63          |

### Table 4. ANOVA for Regression value

| Factor | SS        | Dof | MS    | % Contribution |
|--------|-----------|-----|-------|----------------|
| Feed   | 5.4E-05   | 2   | 3E-05 | 0.03           |
| Speed  | 0.011793  | 2   | 0.0059| 6.41           |
| Doc    | 0.172043  | 2   | 0.086 | 93.56          |
| Error  | 0.004     | 2   | 0.002 | 0.00           |
| Total  | 0.18389   | 8   |       | 100.00         |
Table 5 ANOVA for Mamdani values

| Factor | SS    | Dof | MS    | % Contribution |
|--------|-------|-----|-------|----------------|
| Feed   | 0.018021 | 2   | 0.009 | 7.66           |
| Speed  | 0.003211  | 2   | 0.0016| 1.36           |
| DoC    | 0.209145  | 2   | 0.1046| 88.91          |
| Error  | 0.004      | 2   | 0.002 | 2.06           |
| Total  | 0.235232  | 8   |       | 97.94          |

Figure 9. Optimal value

7. CONCLUSION

From this article, it can be carried out that for the end milling process, Mamdani FIS and regression characteristics correspondingly, however, permit the end milling process at the complete potential the usage of the Mamdani Type FIS model. While the FIS's structure is the same, the Mamdani Type output club capabilities can be both consistent and linear, and for each FIS, the crisp output is likewise created in numerous ways. The gain of the regression is that to customize the controller to human users, it can be paired with neural networks and regression is different optimization approaches. Depth of cut is the most influencing parameter for a minimum surface finish which is followed by speed and depth of cut. Optimal parameters for minimum surface roughness are Feed rate = 40 mm/min, Spindle speed = 85 rpm, and Depth of cut = 1.50 mm.

REFERENCES

[1] Zadeh, L. A. 1965. Information and control, Fuzzy sets 8(3): 338-353.
[2] Hashmi, K., et al. 2000. Fuzzy logic-based data selection for the drilling process. Journal of Materials Processing Technology 108(1): 55-61.
[3] J. Yen and R. Langari, 2004. Fuzzy Logic. Pearson Education.
[4] K.P. Mohandas and S. Karimulla, 2001. Fuzzy and Neuro-fuzzy modeling and control of non-linear systems”, Second International Conference on Electrical and Electronics.
[5] T. J. Ross, Fuzzy Logic with Engineering Applications. 2010. John Wiley and sons.
[6] G. S. Sandhu and K. S. Rattan, 1997. Design of a Neuro-fuzzy controller, *IEEE International Conference on Systems*, Man, Cybern.

[7] M. Du, T. Fan, W. Su, H. Li, 2008. Design of a new practical expert fuzzy controller in central air conditioning control system, *IEEE Pacific-Asia Workshop on Computational Intelligence and Industrial Application*.

[8] S. Li, J. Liu, J. Liu, 2010. Design on the central air-conditioning controller based on LabVIEW”, *ICCASM IEEE proc.*

[9] Rao T.B., Rama Rao P.V., Bala vamosi V., Surya Chandra Babu A., Venu P., Prince G.L. (2018). ‘Optimization of friction stir welding parameters during welding dissimilar aluminum alloys’, *International Journal of Mechanical Engineering and Technology, 9(5)*, 333-340.

[10] Rao P.K.V., Raghu Kumar B., Saieteja A., Srikar N.S.V., Sreenivasulu V., Adithya Prakash D. (2018). Experimental investigation of thermal stability of carbon nanotubes reinforced aluminum matrix using TGA-DSC analysis, *International Journal of Mechanical and Production Engineering Research and Development, 8(3)*, 161-168.

[11] Sandeep M., Jamaleswara Kumar P. (2019). Optimization of analytical modeling of aluminum-multiwall carbon nanotube composites, *Materials Today: Proceedings, 19*, 837-842.

[12] N. Tamiloli, J. Venkatesan, G. Murali, 2019. Shyam Prasad Kodali, T. Sampath Kumar, M. P. Arunkumar; Optimization of end milling on Al–SiC fly ash metal matrix composite using Topics and fuzzy logic, *SN Applied Sciences, 1*:1204, https://doi.org/10.1007/s42452-019-1191-z.

[13] Rajyalakshmi K., Boggarapu N.R. 2019. The expected range of the output response for the optimum input parameters utilizing the modified Taguchi approach. *Multidiscipline Modeling in Materials and Structures, 15(2)*, 508-522.

[14] Luis Pe‘rez, C. J. (2002). Surface roughness modeling considering uncertainty in measurements. *International Journal of Production Research, 40(10)*, 2245–2268.

[15] Azouzi, R., & Gullot, M. (1997). On-line prediction of surface finish and dimensional deviation in turning using neural network -based sensor fusion. *International Journal of Machine Tools and Manufacturing, 37(9)*, 1201–1217.

[16] Hany, F. (2003). Handwriting digit reorganization with fuzzy logic. *Jurnal Teknik Elektro Indonesia, 5*, 84–87.

[17] Sokovowski, A. (2004). On some aspects of the fuzzy logic application in machine monitoring and diagnostics. *Engineering Applications of Artificial Intelligence, 17*, 429–437.

[18] Yesaswi C.S., Subrahmanyam T., Karthik G.S., Sudheer N.S., Basha S.F.2017. Modeling and analysis of a CNC milling machine bed with nanomaterial (Graphene), *International Journal of Mechanical Engineering and Technology, 8(5)*, 372-379.

[19] Kumar R.L., Rao T.E.2018.Inverse kinematics of a 7 DOF space station remote manipulator system (SSRMS) using ANFIS’, *International Journal of Mechanical and Production Engineering Research and Development, 8(0)*, PP. 1364-1375.

[20] Ramya K., Koneru S., Santhosh Kumar R.2018.Multivariable optimization of surface grinding process using genetic algorithm, *International Journal of Mechanical and Production Engineering Research and Development, 8(2)*, 477-486.

[21] Patel P., Nakum B., Abhishek K., Rakesh Kumar V., Kumar A.2018. Optimization of surface roughness in plasma arc cutting of AISI D2 steel using TLBO, *Materials Today: Proceedings, 5(9)*, 18927-18932.

[22] Ram Prasad A.V.S., Ramji K., Raghu Kumar B.2018.Study of wire-electrical discharge machining parameters of titanium alloy by using Taguchi method, *International Journal of Engineering and Technology(UAE). 7(2)*, PP. 10-12

[23] A. Haman, N. D. Geogranas. 2008. Comparison of Mamdani and Sugeno Fuzzy Inference Systems for Evaluating the Quality of Experience of Haptic Audio-Visual Applications”, *HAVE 2008 – IEEE International Workshop on Haptic Audio-Visual Environments and their Applications*.

[20] M. S. I. Md., S. Z. Särker, K. A. A. Rafi, M. Othman, 2006. Development of a fuzzy logic controller algorithm for air conditioning system”, *ICSE Proceedings*. 
