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   NIDN : 0309027603
   Program Studi : Pembuatan Peralatan dan Perkakas Produksi, Politeknik Astra

adalah dosen yang sedang melakukan penelitian di lingkungan Program Studi Pembuatan Peralatan dan Perkakas Produksi Politeknik Astra dengan judul

"***Early Warning Model of Energy Consumption Anomalies for Estimating Real-time Cutting Tools Condition.***"

Surat keterangan ini dibuat untuk keperluan administrasi laporan kinerja dosen di lingkungan Kopertis III. Demikian surat ini dibuat dengan sebenar-benarnya agar dapat digunakan sebagaimana mestinya.

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2nd Mandalika International Multi Conference on Science and Engineering 2023

LETTER OF ACCEPTANCE

Dear Respected Author(s)

It is pleasure to inform you that your submission (with detail below) is accepted at the 2nd MIMSE 2023 that held on November, 28-30th, 2023 in Lombok, Indonesia

Author(s) : Yohanes Wibowo, Nurhadi Siswanto and Mokh Suef
Title : Early Warning Model of Energy Consumption Anomalies for Estimating Real-time Cutting Tools Condition
Paper ID : 133

Information for Author(s), Please read very carefully,

1. All participants must complete the registration fee within 3 days *(Details of fee category could be seen in the appendix)*
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3. All presenter and participants are invited to join in the WhatsApp Group for more information https://chat.whatsapp.com/I47HPsXPZjRAFTsxxhSqSG
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On behalf of the organizing committee of the 2nd MIMSE 2023, we would like to congratulate you on the acceptance of your paper and for participating in this conference. Details information regarding the conference will be informed through the website and your registered email.

Sincerely
Lombok, October 20, 2023

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Early Warning Model of Energy Consumption Anomalies for Estimating Real-time Cutting Tools Condition

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Abstract. Energy consumption is a concern for industry and all parties in the world, especially when energy consumption becomes part of the cost of the production process. An increase in energy costs risks eroding company profits, so it must be maintained. The increase in energy consumption is triggered by the increasing wear of cutting tools so that the replacement of worn cutting tools as much as possible is done at the right time. The obstacle is that the wear of cutting tools cannot be monitored in real time. So, an accurate wear of cutting tools prediction model is needed. In this study, traditional regression models were applied to artificial neural network frameworks to obtain accurate predictions by utilizing independent variables and dependent variables simultaneously. Based on the results of empirical research and numerical simulations, the proposed model shows good predictive ability, with an average model accuracy of 71%. The proposed prediction model is better than traditional regression in terms of accuracy and deviation with confirmation of RMSE values of 8.83%, MAPE 29.1%, R-Square 0.6, and r 0.8. The regression method applied to the artificial neural network framework is able to estimate wear of cutting tools so that efforts to maintain the level of energy consumption as part of the green machining business can be done properly.

Keywords: Wear of Cutting Tools, Electric Current, Energy Consumption, Prediction Model

1 Introduction

Good quality is an industry objective that requires a long and repetitive process to achieve [1]–[3]. Various variables influence objective achievement. Many objectives encourage the emergence of priorities or studies to simplify objectives. This study focused on energy consumption in relation to wear of cutting tools, machining time, and costs. The broader scope of this study is about energy in green machining[4]–[7]. The study objective is specifically to get a model that can sense the change in energy consumption as an impact of the wear of cutting tools. The change over energy that rises as long as the wear of cutting tools will recognised as an energy consumption anomaly.

This anomaly should then be responded to properly to keep the energy consumption low and to maintain the cost stable as planned.

The percentage of energy costs to machining costs is about 20%, and when the machine is in maintenance condition, it still costs up to 4%[2]. In machining, energy consumption increases intensely as the cutting force increases in response to the onset of the wear of cutting tools [8], [9]. The impact of the wear of cutting tool is that dimensions are not achieved [10]. A further impact is the non-fulfillment of safety aspects and the emergence of rework, which has the potential to increase costs by 39%[2]. Considering the implications of the wear of cutting tools, we can see the importance of this topic.

Although the impact of wear is very large, monitoring the wear of cutting tools is not carried out because it is impractical and is influenced by various variables and other factors [11]. Corrective action against the wear of cutting tools is easy to perform despite the large cost and time impact. Many studies are related to the wear of cutting tools but have not been applicable [12]. Thus, a needed prediction model that can estimate the wear of cutting tools in real time is the motivation for this study. With the wear of cutting tools prediction model, the quality achievement process will be controlled, and the process of reworking as the impact of quality mismatch can be minimized. The concept of green machining is applicable [4]. The implications of this model will be broad and numerous according to the population of milling machines as machine tools with the largest population in the industry [13].

Although many studies are related to prediction models, existing models involve only independent variables as the basis for prediction [14]–[17]. This study is more challenging because it involves input and response variables simultaneously as the basis of the prediction model. This model resembles a prediction model based on artificial neural networks that use input and response variables simultaneously to get the final response. This study used traditional regression incorporated in the framework of artificial neural networks to obtain reliable predictions.

With this model, the estimated wear of cutting tools will be closer to the actual value because it is assisted by the response of energy consumption in real-time. The prediction criteria used are correlation coefficient, root mean square error, mean absolute percentage error, and determination coefficient [18], [19]. Considering that experimental research to obtain primary data is expensive and requires a lot of time and effort, the proposed predictive model should be friendly to small data. Traditional regression situated into artificial neural network frameworks is expected to answer the need for precise and data-friendly models. Good solutions are expected to emerge from this approach because models are tested through simulative and practical demonstrations through examples of industrial experiments.

2 Method

2.1 Materials and Measurement

S45C carbon steel material specimens are used in dry milling machining. The CNC milling machine used is the Makino (KE55, Singapore, 2011). The specimen size is

200 mm x 150 mm x 60 mm, and the cutting tools used are TAPR300R-2020-160 with APMT1135PDER series carbide insert cutting edges. To ensure the similarity of machining qualities, in each machining process, a new carbide insert is used. For energy consumption measurement, current monitoring is monitored using a Precision Power Analyzer (Yokogawa WT1800, Japan, 2015). Measurement of the wear of cutting tools are carried out using a microscope (Nikon Eclipse LV150, Japan, 2018).

Homogeneity tests are performed before the machining process to ensure the repeatability of this method. Homogeneity tests are performed to ensure the similarity of material properties of specimens to be tested by following the ISO 8688 standard on tool life testing[20].

2.2 CNC Milling Parameters

Machining parameters are values that are informed into the machining process to influence the machining process so that a product is produced as needed. CNC milling parameters are independent variables in the machining process. The chosen inputs for this study are Axial Depth of Cut (Ap), Radial Depth of Cut (Ae), Feedrate (F), and Spindle rotation (n). These parameters have four levels. The selection of values for these levels was informed by a literature review, aiming to optimize the process for efficiency and accuracy while minimizing data usage [21]. Ap is the variable for representing how deep the cutting tool goes down into the material in a vertical direction. Ae represents the distance of cutting tools movements in a horizontal direction. Feedrate represents the rate at which the cutting tool goes forward and cuts the material. The spindle rotation represents how fast the cutting tools rotate.

Wear of cutting tools (TW) and electric current (EC) are selected in response. Electric current is a response that will be used together with machining parameters to predict the final response, namely wear of cutting tools.

2.3 Artificial Neural Network Framework

In the context of an Artificial Neural Network (ANN), inputs and outputs are linked through complex mathematical functions that are nonlinear [22]–[24]. The ANN architecture consists of various layers, such as input, hidden layer, and output. The connections among inputs, neurons, and outputs can acquire and assimilate information through learning processes. [25], [26].

Cybenko’s theory states that a network with one hidden layer and many neurons is often sufficient to reach the appropriate level of accuracy [27]. In most circumstances, a single hidden layer suffices to solve the problem at hand. Electric current serves as neurons in the hidden layer in this investigation. The electric current influences the response of the wear of cutting tools. The ANN architecture is depicted in detail, with four neurons in the input layer, one in the hidden layer, and one in the output layer. Within the ANN framework, the interactions between the input layer and the hidden layer, as well as the hidden layer and the output layer, will be represented using a regression technique.

2.4 Numerical Simulation

The regression model used in numerical simulation is a model based on response surface methodology (RSM). RSM regression was chosen because this method is a combined method of statistics and operational research that is believed to be able to provide better performance [28]. In this method, the relationship between the input variable and the response variable on the hidden layer will be modeled to get the output.

2.5 Process Steps

Procedural steps were organized into four groups: a) completing the experimental process of CNC milling operations to obtain response values for predetermined parameters, b) conducting numerical simulations for the regression method, c) performing numerical simulations of the regression methods applied into the ANN framework, d) observing the prediction performance of proposed model comparing between traditional method.

3 Result and Discussion

3.1 Experimental Dataset

All independent variables in the empirical study and dependent variables consisting of electric current and wear of cutting tools are the outcomes of this study. They are stored and displayed in Table 1.

Table 1. Experimental Research Result

Test Run	Axial Depth of Cut (mm)	Radial Depth of Cut (mm)	Feed rate (mm/min)	Spindle Speed (rpm)	Current (A)	Wear of Cutting Tools (mm)
1	0.2	5	200	300	4.22	0.021
2	0.2	9	300	600	4.46	0.056
3	0.2	12	400	800	4.97	0.085
4	0.2	16	500	1000	5.45	0.109
5	0.5	5	300	800	4.62	0.186
6	0.5	9	200	1000	4.72	0.254
7	0.5	12	500	300	5.05	0.024
8	0.5	16	400	600	4.95	0.065
9	0.8	5	400	1000	5.09	0.092
10	0.8	9	500	800	5.77	0.113
11	0.8	12	200	600	5.55	0.130
12	0.8	16	300	300	5.82	0.145

13	1.0	5	500	600	5.47	0.160
14	1.0	9	200	600	5.47	0.135

3.2 Numerical Simulation

This section contains mathematical models of two regression models, namely the traditional regression model (TW1), which uses four independent variables only as the basis for calculation, and the mixed regression model (TW2), which uses four independent variables and the response of electric current as the basis for calculations as displayed in equations 1 and 2. The variables used in these equations were described in the CNC Milling Parameters section. The results of the numerical simulation are shown in Figure 1.

$$TW_1 = -0{,}3145 + 1{,}415*Ap - 0{,}002252*Ae + 0{,}001273*F - 0{,}000231*n - 0{,}6078*Ap*Ap - 0{,}002084*Ae*Ae - 0{,}000004*F*F + 0{,}000000*n*n - 0{,}01242*Ap*Ae + 0{,}001282*Ap*F - 0{,}001229*Ap*n + 0{,}000049*Ae*F + 0{,}000044*Ae*n \quad (1)$$

$$TW_2 = -1{,}471 - 0{,}004052*Ap - 0{,}04432*Ae - 0{,}001832*F + 0{,}000858*n + 0{,}7510*EC + 0{,}09766*Ap*Ap + 0{,}000428*Ae*Ae + 0{,}000002*F*F + 0{,}000000*n*n - 0{,}08242*EC*EC + 0{,}06116*Ap*Ae + 0{,}000708*Ap*F - 0{,}001163\ Ap*n \quad (2)$$

Fig. 1. Wear of Cutting Tools Response Value and The Proposed Prediction Model Result

3.3 Discussion

Based on the description of empirical research and numerical simulations, it clearly can be seen that prediction models utilizing response variables provide better results than input-only variables. Prediction models involving response variables are called mixed models, whereas prediction models involving only independent variables are called traditional models. The deviation of traditional prediction models looks larger, as shown in Figure 2. This finding reinforces the theory that the response variables involved in predictions improve the prediction performance clearly and convincingly. In industry, this response variable is taken from the sensor.

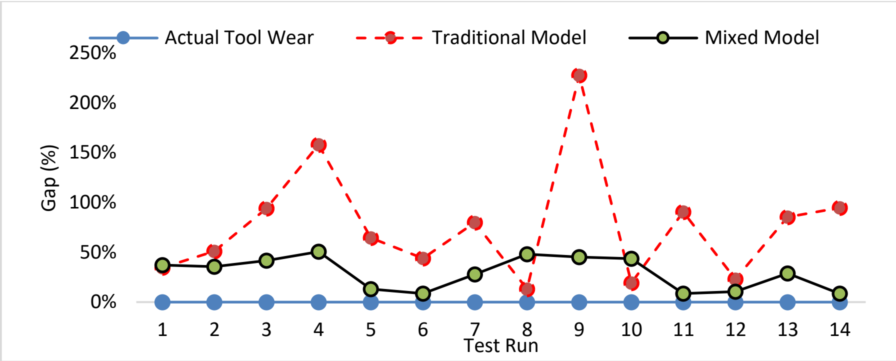

Fig. 2. Prediction Deviation Between Traditional and Mixed Method

Apart from the low deviation, prediction performance is also seen from the level of accuracy of the model. Mixed models provide better predictive performance accuracy than traditional models, as presented in Figure 3. Mixed model accuracy spread from 49-91% with an average of 71%.

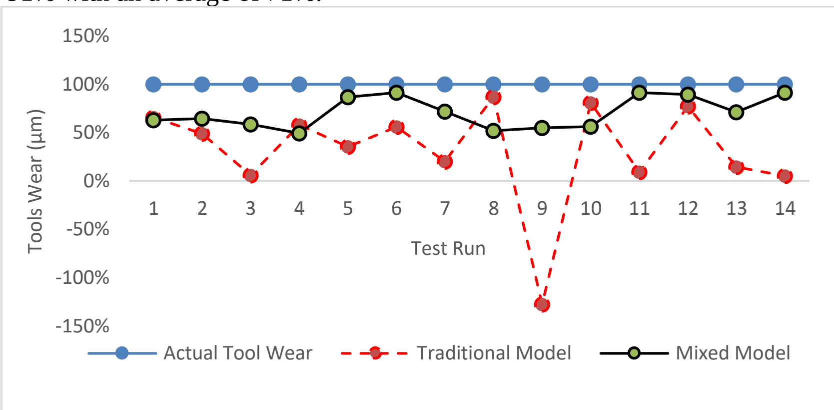

Fig. 3. Prediction Accuracy Between Traditional and Mixed Method

Based on the description of accuracy, deviation, and prediction results, traditional regression models worked on artificial neural network frameworks are able to produce better performance [29]. Mixed model performance is boosted with RMSE values of 8.83%, MAPE 29.1%, R-Square 0.6 and r 0.8 [30]. RMSE measures how close the model predictions are to the observed values, where smaller is better. MAPE indicates the model's relative error in predicting. MAPE figure below 20% is in the good criteria, while 20-50 means quite good. R-Square measures how well the data varies with a value between 0-1. Number 1 means perfect model. A positive r value indicates a positive direction of the relationship. When r approaches 1, the model shows a perfect relationship. With this model, the increase in energy consumption initiated by electric current represents an increase in the wear of cutting tools [1]. By standardizing the range of electric current consumption, the rework process due to the wear of cutting tools can be suppressed so that green machining will be carried out [4]. In short, the mixed model provides better performance in terms of prediction since it involves both input variables and response compared to the traditional model, which involves input variables only.

4 Conclusion

This study seeks to find a predictive model that uses the independent variable and the dependent variable as the basis for calculation. The proposed mixed model implements traditional regression into the ANN framework, can demonstrate accurate predictions, and has low deviations. In addition to being displayed through figures, performance was also validated with RMSE values of 8.83%, MAPE 29.1%, R-Square 0.6, and r 0.8. The model conclusively provides answers to the need for accurate models to identify energy consumption anomalies in real time on processes in CNC milling. The economic implications are a decrease in process costs due to maintained levels of energy consumption, a decrease in the rework process due to the recognition of the level of wear of cutting tools in real-time, and the creation of energy-friendly green machining.

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"2nd MIMSE MANDALIKA INTERNATIONAL MULTI-CONFERENCE ON SCIENCE AND ENGINEERING 2023"

Raja Hotel Kuta Mandalika, Lombok

28 - 30 November 2023

Rector

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Chairman of MIMSE

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