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Forecast of the Temperature Variation of an Elastohydrodynamic Contact by the Simple Exponential Smoothing Model (SES)

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Abstract: Lubrication is a crucial tool for industrial maintenance. By reducing friction between components, it also reduces wear on equipment.
Industrial lubricants have specific properties and can operate efficiently within their operating temperature range. The aim of this study is therefore to forecast the temperature variation of lubrication oil using simple exponential smoothing.
In this paper, we discuss one of the most popular forecasting methods in engineering and mechanical fields. The exponential smoothing method has been successful due to the quality of the results it presents. The present contribution aims to model the temperature variation of lubricating oil in a mechanical contact by the simple exponential smoothing method. The analysis and examination of the set of results made it possible to compare the smoothing models for different values of α and to choose the model closest to the actual temperature curve, the choice of the closest model serves to calculate the optimization criteria for the forecast; this method consists in choosing the α minimizing. The forecast results obtained by the SES model with α=0.9 are judged very satisfactory, and they prove the dominance of the SES model

Keywords: Short-term forecasting; Lubricant; Temperature variation; Exponential smoothing; Time series.

1. Introduction

The forecasting activity is the starting point for planning. As one moves further into the planning horizon, forecasting is difficult. However, it is better to forecast, even with uncertainty, than not to forecast [1].

The choice of a forecasting method is essentially based on the information set, it means the information available and that one wants to exploit. The forecast origin is T and the forecast horizon is h.

The forecast of the unknown future value y_T+ h is noted by: $\hat{y}_{T(h)}$ [2].

Many materials or systems deteriorate over time before the failure. In order to model these degradations and to better understand the causes of failure of these systems or materials, we need to develop models to describe the degradation of the systems; these models have a major interest because they allow understanding the dynamics of degradation. Moreover, they play a crucial role when it comes to improving the reliability and maintenance policy of systems.

Stochastic processes, which allow the modeling of systems whose behavior is only partially predictable. The theory is based on the calculation of probabilities as well as statistics [3].

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Modeling is the subject of our study because it allows us to have access to the behavior of the system, "priory" behavior in terms of probability of occurrence: probability of breaking down at each moment, probability of being in the given state of degradation as a function of the time [4].

The state's leading to system failure are usually modeled in one of the following ways [5]: either as a "white box" which corresponds to a conceptual model, or as a "black box" which is an empirical model and finally as a "grey box" which corresponds to a stochastic approach.

In this study we are particularly interested in time series: simple exponential smoothing, which has seen a significant development.

Simple exponential smoothing methods date from the early 1960s. The simplicity of these methods and their low cost in spite of the performance they provide amply justify their use; simple exponential smoothing is a short-term forecasting method of the extrapolation method family, which consists of extending past trends. It was founded by Brown in 1962 and generalized by Holt and Winters in 1963.

The aim of this work is to associate a mathematical model with the results obtained when the temperature of the two surfaces in contact is varied by unpolluted oil, using an infrared thermocouple. This work has an effective impact compared with current published work because it opens the door to the wide use of time series and the possibility of modeling different phenomena that vary as a function of time.

Firstly, using an infrared thermocouple, the temperatures at the contact point of the surfaces are measured as a function of time. The measurements were made for lubrication with unpolluted oil.

Then the temperature prediction is calculated using the simple exponential smoothing model for α varies between 0 and 1.

To choose the forecast closest to the actual temperature values, we calculate the optimization criteria such as the mean square error MSE, the mean absolute error MAE, the mean absolute percentage error MAPE.

Finally, the validation of the smoothing model with α=0.9, which provided accurate estimates close to the true value and better than the model with α=0.8.

2. Modeling Using Simple Exponential Smoothing

Our purpose is to briefly present the main theoretical elements related to the exponential smoothing model and for more details see [6].

This model is also sometimes called Brown's simple exponential smoothing, and it predicts a value based on past data by assigning a lower weight to the data the further back in time they correspond. The weighting evolves exponentially, hence the name of the model.

This method is probably the best known for forecasting the evolution of certain significant parameters of the state of systems. The forecast for period n is that of period n-1 corrected in proportion to the difference

(D_{n-1} - F_{n-1}) between actual demand and the forecast that was made for the previous period:

$$F_n = F_{n-1} + \alpha\left(D_{n-1} - F_{n-1}\right) \tag{1}$$

Where α is the smoothing constant between 0 and 1 [7].

$$If \begin{cases} \alpha = 0, & \text{it is considered that } f_n = f_{n-1} \\ \alpha = 1, & \text{it is considered that } f_n = D_{n-1} \end{cases} \tag{2}$$

Otherwise, we say:

$$F_{t+1} = \alpha D_t + (1-\alpha) F_t \tag{3}$$

– Like any filter, simple exponential smoothing "clips" the irregularities in the series.

– Simple exponential smoothing is a linear filter.

– Like the moving average, simple exponential smoothing adapts with delay to a change in the level of the series. The stability and response rate of the smoothed series depend on the value of the smoothing constant α, and these two characteristics have a complementary aspect [8].

3. The Choice of the Smoothing Constant

The selection can be made according to subjective criteria of "rigidity" or "flexibility" of the forecast. But a more objective method is to choose α that minimizes the squared error and the mean forecast error [8]:

Mean Square Error:

$$MSE = \frac{1}{T-1}\sum_{t=1}^{T-1}\left(x_{t+1} - \hat{x}_t\right)^2 \tag{4}$$

Mean Absolute Error MAE:

$$MAE = \frac{1}{T-1}\sum_{t=1}^{T-1}\left|x_{t+1} - \hat{x}_t\right| \qquad (5)$$

Mean error:

$$ME = \frac{1}{T-1}\sum_{T=1}^{T-1}\left(x_{t+1} - \hat{x}_t\right) \qquad (6)$$

4. Forecast of temperature variation by the Simple Exponential Smoothing model

4.1. Working methodology

An experimental device is used to ensure that the experiment is conducted correctly (Figure 1). This is a device in which two surfaces are brought into contact with each other and supplied with unpolluted oil; using an infrared thermocouple.

The temperatures are measured as a function of time at the point of contact of the two surfaces (Figure 2). The measurements were carried out for unpolluted oil [9].

The results of the temperature variation between the surfaces in contact, for a rotation speed of 250 rpm and a load of 180 N, are measured with an infrared thermocouple, and are presented in Figure 3.

4.2. Discussion of the modeling results

The possible results of the temperature forecasts for an α varied between 0 and 1 are presented in Table 1, and to choose the forecast nearest to the actual temperature values, the optimization criteria are calculated according to equations 4, 5 and 6.

Figure 1: (a) The experimental device. (b) Infrared thermocouple [9].

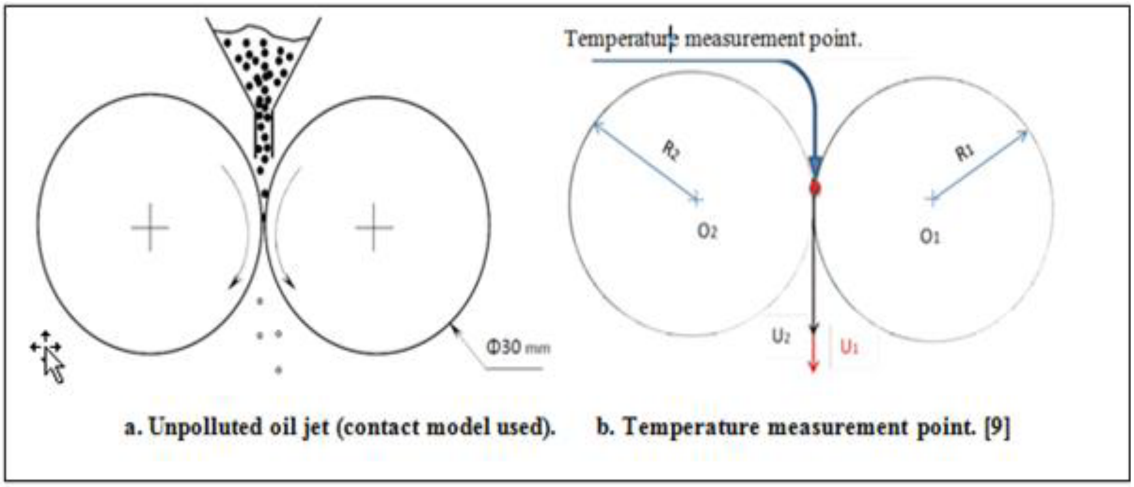

Figure 2: The experimental principle; (a) unpolluted oil jet. (b) Temperature measurement point.

Table 1: Forecasting temperature variation by exponential smoothing with α from 0 to 1.

Time	Actual values	Temperature forecast (SES)				
		α=0	α=0.3	α=0.6	α=0.8	α=0.9
1	27	27	27,00	27,00	27,00	27,00
2	27,4	27	27,00	27,00	27,00	27,00
3	27,6	27	27,12	27,24	27,32	27,36
4	27,8	27	27,26	27,46	27,54	27,58
5	28	27	27,42	27,66	27,75	27,78
6	28,2	27	27,60	27,86	27,95	27,98
7	28,4	27	27,78	28,07	28,15	28,18
8	28,8	27	27,96	28,27	28,35	28,38
9	28,8	27	28,22	28,59	28,71	28,76
10	29,2	27	28,39	28,71	28,78	28,80
11	29,6	27	28,63	29,01	29,12	29,16
12	29,8	27	28,92	29,36	29,50	29,56
13	30	27	29,19	29,62	29,74	29,78
14	30,2	27	29,43	29,85	29,95	29,98
15	30,4	27	29,66	30,06	30,15	30,18
16	30,8	27	29,88	30,26	30,35	30,38
17	31	27	30,16	30,59	30,71	30,76
18	31,2	27	30,41	30,83	30,94	30,98
19	31,4	27	30,65	31,05	31,15	31,18
20	31,4	27	30,87	31,26	31,35	31,38
21	31,4	27	31,03	31,34	31,39	31,40
22	32	27	31,14	31,38	31,40	31,40
23	32	27	31,40	31,75	31,88	31,94
24	32	27	31,58	31,90	31,98	31,99
25	32	27	31,71	31,96	32,00	32,00
26	32	27	31,79	31,98	32,00	32,00
27	32	27	31,86	31,99	32,00	32,00
28	32	27	31,90	32,00	32,00	32,00
29	32	27	31,93	32,00	32,00	32,00
30	32	27	31,95	32,00	32,00	32,00

According to the set of forecast models for different values of α (Figure 4), we remark that the forecast for an α = 0 is imperceptible, but the forecast for an α = 0.8 and 0.9 is close to the actual values of the temperature and in order to distinguish the most pertinent forecast, we have to calculate the optimization criteria of the forecast; this method consists to choose the α which minimizes the optimization criteria.

In the Setting of the temperature forecast by exponential smoothing, three optimization criteria are used to compare the two models with the two values of α (0.8, 0.9):

Mean Square Error MSE, Mean Absolute Error MAE, Mean Absolute Percentage Error MAPE, the results of the optimization criteria are mentioned in Table 2.

Table 2: Optimization criteria of temperature forecast for α=0.8 and 0.9.

Time	Actual (Real) values	α = 0.8				α = 0.9			
		Forecast	Absolute Error	Error ^{2}	APE	Forecast	Absolute Error	Error ^{2}	APE
1	27	27,00	0,00	0,00	0,00	27,00	0,00	0,00	0,00
2	27,4	27,00	0,40	0,16	1,46	27,00	0,40	0,16	1,46
3	27,6	27,32	0,28	0,08	1,01	27,36	0,24	0,06	0,87
4	27,8	27,54	0,26	0,07	0,92	27,58	0,22	0,05	0,81
5	28	27,75	0,25	0,06	0,90	27,78	0,22	0,05	0,79
6	28,2	27,95	0,25	0,06	0,89	27,98	0,22	0,05	0,79
7	28,4	28,15	0,25	0,06	0,88	28,18	0,22	0,05	0,78
8	28,8	28,35	0,45	0,20	1,56	28,38	0,42	0,18	1,47
9	28,8	28,71	0,09	0,01	0,31	28,76	0,04	0,00	0,15
10	29,2	28,78	0,42	0,17	1,43	28,80	0,40	0,16	1,38
11	29,6	29,12	0,48	0,23	1,63	29,16	0,44	0,19	1,49
12	29,8	29,50	0,30	0,09	1,00	29,56	0,24	0,06	0,82
13	30	29,74	0,26	0,07	0,86	29,78	0,22	0,05	0,75
14	30,2	29,95	0,25	0,06	0,83	29,98	0,22	0,05	0,74
15	30,4	30,15	0,25	0,06	0,82	30,18	0,22	0,05	0,73
16	30,8	30,35	0,45	0,20	1,46	30,38	0,42	0,18	1,37
17	31	30,71	0,29	0,08	0,94	30,76	0,24	0,06	0,78
18	31,2	30,94	0,26	0,07	0,83	30,98	0,22	0,05	0,72
19	31,4	31,15	0,25	0,06	0,80	31,18	0,22	0,05	0,71
20	31,4	31,35	0,05	0,00	0,16	31,38	0,02	0,00	0,07
21	31,4	31,39	0,01	0,00	0,03	31,40	0,00	0,00	0,01
22	32	31,40	0,60	0,36	1,88	31,40	0,60	0,36	1,88
23	32	31,88	0,12	0,01	0,38	31,94	0,06	0,00	0,19
24	32	31,98	0,02	0,00	0,08	31,99	0,01	0,00	0,02
25	32	32,00	0,00	0,00	0,02	32,00	0,00	0,00	0,00
26	32	32,00	0,00	0,00	0,00	32,00	0,00	0,00	0,00
27	32	32,00	0,00	0,00	0,00	32,00	0,00	0,00	0,00
28	32	32,00	0,00	0,00	0,00	32,00	0,00	0,00	0,00
29	32	32,00	0,00	0,00	0,00	32,00	0,00	0,00	0,00
30	32	32,00	0,00	0,00	0,00	32,00	0,00	0,00	0,00
			MAE = 0,21	MSE= 0,07	MAPE = 0,70		MAE = 0,19	MSE= 0,06	MAPE= 0,63

Table 3: Comparison between the optimisation criteria values of the temperature.

For α = 0.9 and 0.8

Values of α	MAE	MSE	MAPE
0,8	0,21	0,07	0,70
0,9	0,19	0,06	0,63

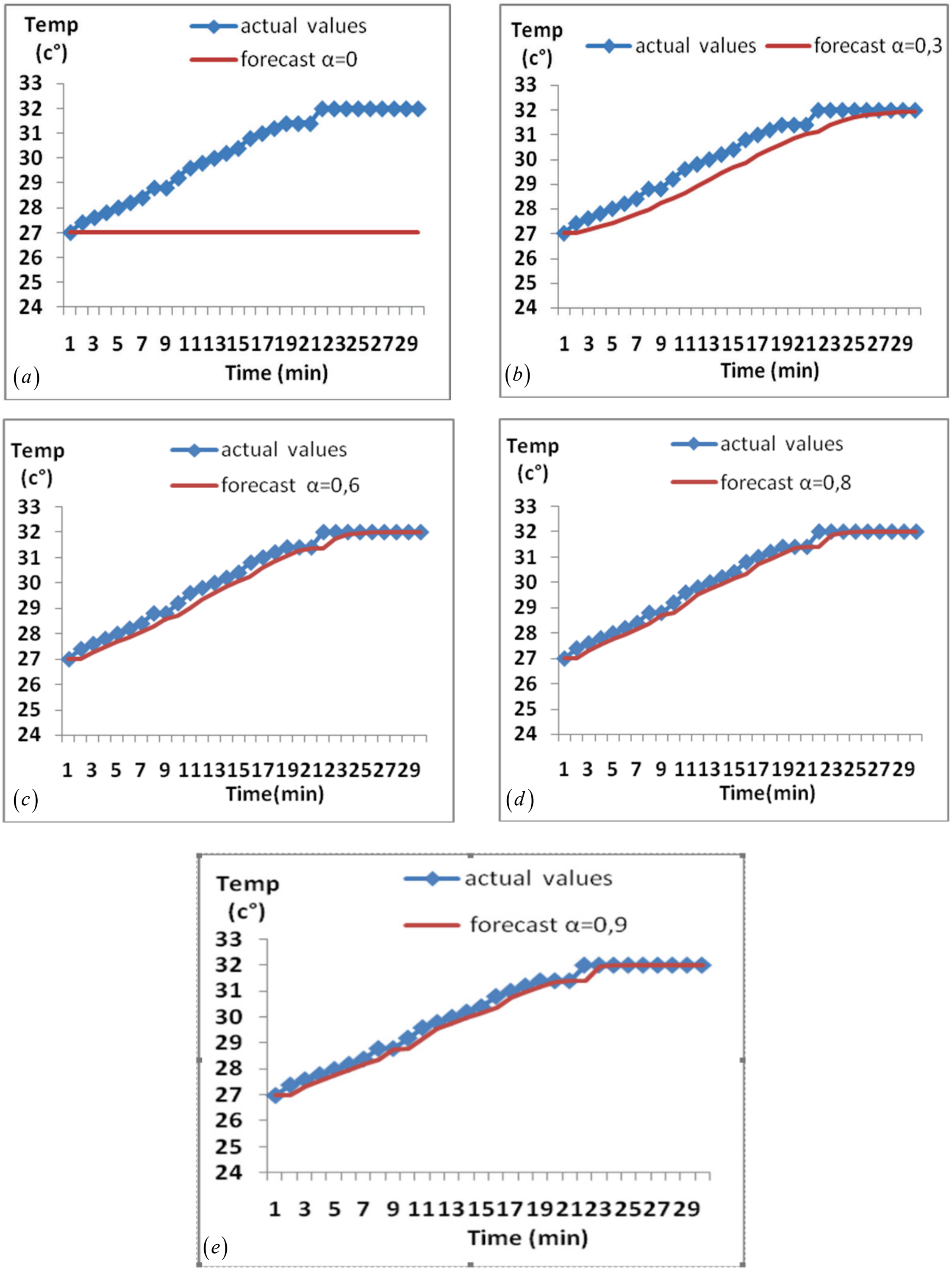

Figure 4: Forecasting models of Temperature with different values of α: (α = 0, …., 0.9).

From Table 3, we can see that the results are acceptable and that the calculation of MAE, MSE and MEPA for α = 0.9 is minimal, so the closer α is to 1, the greater the influence of the observations that are distant in time from the base n. The smoothing model with α = 0.9 provides accurate estimates that are close to the actual value compared to the forecast of α = 0.8.

The smoothing model with α = 0.9 provides accurate estimates close to the true value compared to the forecast of α = 0.8.

From Table 3, we can see that the results are considered acceptable and that the results of MAE, MSE and MEPA for α = 0.9 is minimal; when α is closer to 1, the influence of observations are farther away in time from the base n is greater.

The smoothing model with α = 0.9 provides accurate estimates close to the actual values as compared to the forecast of α = 0.8.

5. Conclusions

Lubrication is an imprecise science that relies heavily on experience and empiricism. It represents a set of techniques that allow the reduction of friction and wear between two elements in contact and in movement with each other by applying lubricants.

For this purpose, we are interested in modeling the behavior of contact lubricants by using time series, as it allows us to provide an acceptable prediction model.

The examination of the forecast data of the temperature variation of the lubricating oil confirmed the compatibility of the SES model and probably provides a more reliable statistical model to make predictions on the behavior of the system studied.

The use of different time series analysis techniques provides a better understanding of the degradation mechanisms and it also enables us to validate the exponential smoothing model and prove its efficiency.

Thus, a new approach dedicated to researchers to enrich their fields of experience and adopt decision support tools whose main objective is to improve product quality.

And as a perspective we propose the use of time series in particular the exponential smoothing as a tool of help to the decision for the industrial maintenance and planning.

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