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Development of Model for Heating Process of Herb Drying Based on Linear System Identification

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Abstract: The development of drying herbs by heating is a dynamic process that can be described and optimized using linear system identification. This method involves collecting data from the system, such as temperature and humidity, and using it to identify mathematical models that characterize the system's behaviour. Specifically, the ARX (AutoRegressive with Exogenous inputs) and ARMAX (AutoRegressive with Exogenous inputs and Moving Average) models are commonly used in this process. These models involve using historical data on the system's inputs and output to make predictions and identify relationships between the different variables. After a model has been identified, it can be utilized to make predictions regarding the system's reaction to various inputs and conditions, such as variations in the system's temperature or humidity. This can help to improve the quality, energy conservation, and efficiency of the drying process. However, traditional open-loop or linear control systems lack the necessary feedback capability, which can lead to a reduction in the shelf life of the herbs. Therefore, it is important to study and compare different pre-drying and drying procedures to find the best method for each type of herb. The main goal of this paper is to collect data, create a mathematical model based on linear system identification using ARX and ARMAX models, and propose a controller that can automatically control the temperature of the herb drying process.

Keywords : Linear System Identification, Mathematical Model, ARX, ARMAX

1. Introduction

Various methods for drying herbs have been created over the last few decades due to the research conducted on the topic. On the other hand, commercially dried herbs to the fresh variety. In this paper, a synopsis of the various technological strategies developed to enhance the quality of aromatic herbs for their industrial drying is provided by examine the impact of drying techniques and pre-drying treatments on the aroma and appearance of dried herbs [1]. This statement is true, however, there is more work to be done to improve the quality of herbs that can be dried. This is because the development

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of controllers is important before creating or developing technologies for dryers. This is because the herbs retain a high quantity of moisture even while they are dried at high temperatures [2]. It is advised and suitable to develop a controller using a linear system identification (ID) since this is the optimum experimental design for producing high-quality data for model fitting and model shrinkage.

Linear system identification is a way to model and study dynamic systems, like how herbs dry when they are heated. It involves taking measurements of things like temperature and humidity from the system and using those measurements to find the mathematical models that describes how the system works. This model can then be used to predict how the system will react to changes in temperature or humidity, for example. Most of the time, experimental data collection and mathematical modeling techniques, like regression analysis or state-space modeling, are used together to make a model of the heating process of drying herbs. The method of creating mathematical models of dynamical systems from observed data falls within this area of linear system identification [3]. This method has been validated as an improvement over the canonical parametric technique. The current formulations, however, are not strong enough to handle outliers in linear system identification. In particular, all of the accepted estimators find a solution to a regularized least squares problem, while the form of the penalty term allotted to the impulse response varies between estimators [4].

2. Methodology

The modeling phase in Figure 1, shows the process of selecting the model and how it is done after collecting the data. System identification is similar in many ways, but there are also some key differences. Both ARX and ARMAX models are used for system identification, which is the process of creating a mathematical model that describes the relationship between the input and output of a system. The goal of this phase is to find the best possible model that accurately describes the system's behaviour, typically by minimizing the error between the model's predictions and the actual system outputs.

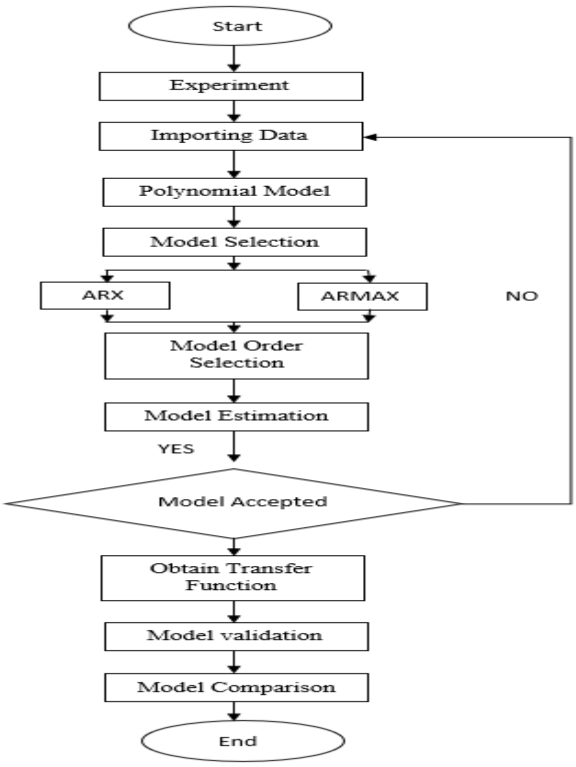

Figure 1: Project flowchart

2.1 System structure for collecting data

Figure 2 shows the block diagram of the connection of the Arduino ESP8266 temperature monitoring system. In this system procedure, the temperature sensor is the input that is hooked up to the Arduino ESP8266. During the drying process, the temperature sensor will measure how fast the heat is rising and send that information to the Arduino ESP8266. Lastly, to monitor the display, the Arduino ESP8266 will connect to a computer. It will then use the right software to get the data. The MATLAB software will be used to connect the simulation to the data that was collected.

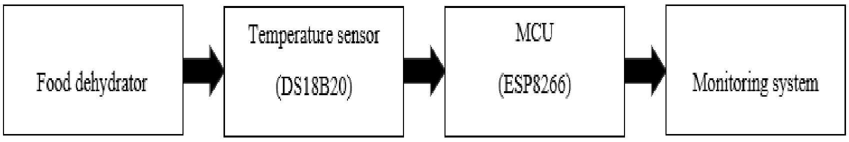

Figure 2: The block diagram of the connection of the Arduino ESP8266 temperature monitoring system.

Based on Figure 2, how the first data was gathered for an open-loop temperature monitoring system for the drying process. In this process, the non-contact temperature sensor DS18B20 is hooked up to the microcontroller ESP8266. Next, the DS18B20 will check the chamber's temperature and send a signal to the ESP8266. Using the C language, the Arduino IDE software is used to program the microcontroller. The ESP8266 will connect to the computer to get the temperature reading, which will be shown on the Arduino IDE serial monitor window. The temperature sensor has been set up with the ideal temperature range for herbs. The temperature sensor detects a temperature value in units of Celsius.

3. Results and Discussion

This section discusses the result, evaluation, and problems encountered during project completion. After the project has been developed and completed, it will be evaluated to measure its effectiveness and ensure that it has successfully met the outlined goals and objectives. Figure 3 shows the step prediction response of ARX model. Meanwhile, Figure 4 shows the step prediction of the highest best-fit model of ARX. To obtain the transfer function of the herb drying system identification using the ARX method is used from MATLAB software. The transfer function is modeled using the input and output values of food dehydrator temperatures respectively. The transfer function is also modeled using 4000 temperature data taken from 1-second intervals.

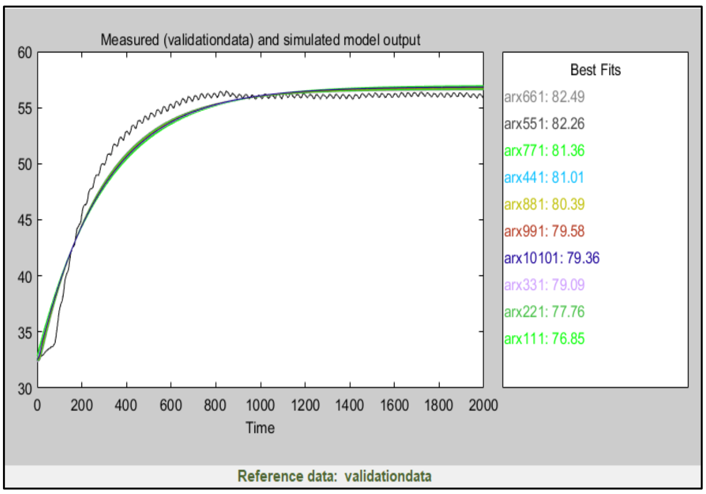

Figure 3: Step prediction response in all ARX order.

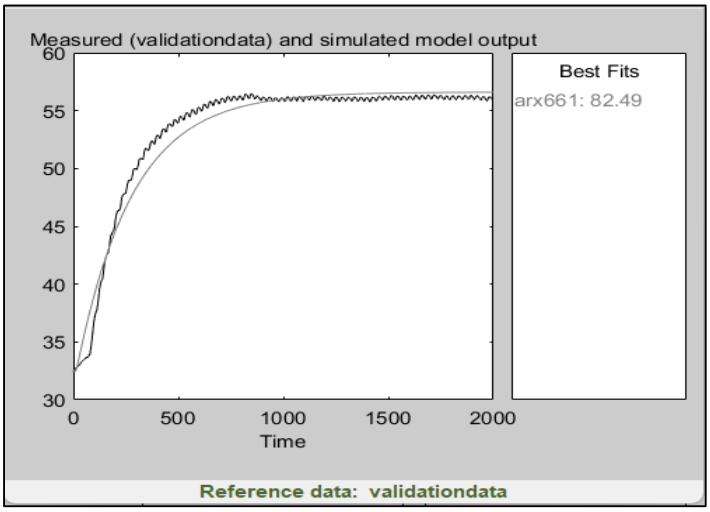

Figure 4: Step prediction ARX model of sixth order.

The discrete transfer function shows the ARX model is derived by the numerator B(z) over the denominator. A(z) is shown in equation 1. Hence, the MATLAB system identification application software obtained the equation for A(z) and B(z). Equation 1 shows the discrete transfer function for the sixth order ARX model and its final prediction error (FPE) and means square error (MSE) are shown as:

$$G(z) = \frac{B(z)}{A(z)} = \frac{1.164}{z^{-6} - 0.9938z^{-5} - 0.03252^{-4} + 0.1614z^{-3} + 0.146z^{-2} + 0.08476z - 0.01555} \quad \text{(Eq.1)}$$

FPE = *0.002083*
MSE = *0.002046*

An ARMAX (AutoRegressive Moving Average with Exogenous inputs) model is a type of time series model that is used to predict future values of an output variable based on past values of the output variable, exogenous inputs, and past values of the errors or residuals. Figure 5 shows the overall order ARMAX model obtained from the system identification simulation. The results show that the ARMAX model best fits 96.5%. Meanwhile, Figure 6 shows the eighth order ARMAX model obtained from the system identification simulation. The results show that the ARMAX model order eighth with the highest best fits at 96.5%.

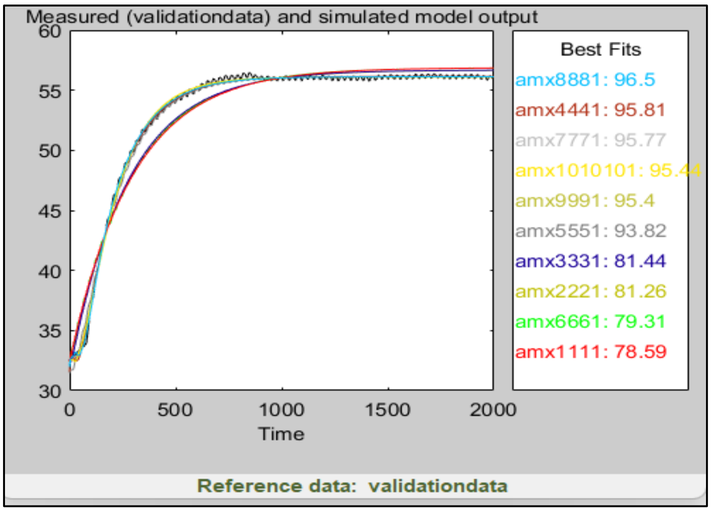

Figure 5: Step prediction response in all ARMAX order.

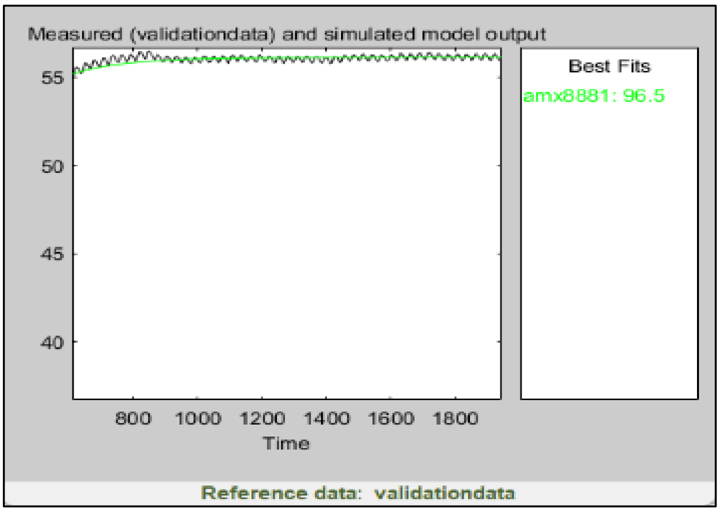

Figure 6: Step prediction ARMAX model of eight order.

The transfer function of the ARMAX model is derived by the numerator C(z) over the denominator A(z) then B(z) over the denominator A(z) is shown in equation 2. Hence, the MATLAB system identification application software obtained equation 2 for A(z), B(z), and C(z). The results for the discrete transfer function for the first order ARMAX model its final prediction error (FPE) and mean square error (MSE) are shown in equation 2:

$$y(k) = \frac{\begin{matrix} 1-1.529z^{-1}-1.157z^{-2} \\ +2.228z^{-3}0.5876z^{-4} \\ -1.344z^{-5}+0.04624z^{-6} \\ +0.1018z^{-7}+0.0699z^{-8} \end{matrix}}{\begin{matrix} 1-2.527z^{-1}+0.1191z^{-2} \\ +3.983z^{-3}-1.655z^{-4} \\ -2.787z^{-5}+1,771z^{-6} \\ +0.5024z^{-7}-0.4058z^{-8} \end{matrix}} u(k) + \frac{\begin{matrix} -0.01406z^{-1}-0.01406z^{-2} \\ -0.01406z^{-3}-0.01406z^{-4} \\ -0.01406z^{-5}-0.01406z^{-6} \\ +0.5696z^{-7}-0.4828z^{-8} \end{matrix}}{\begin{matrix} 1-2.527z^{-1}+0.1191z^{-2} \\ +3.983z^{-3}-1.655z^{-4} \\ -2.787z^{-5}+1,771z^{-6} \\ +0.5024z^{-7}-0.4058z^{-8} \end{matrix}} e(k) \qquad \text{(Eq.2)}$$

FPE = *0.002691*
MSE = *0.00268*

3.1 Comparative Analysis

The validation data is used to evaluate the ability of the model to accurately predict future values based on past data. It is typically presented as a percentage and shows how well the model's predictions match the actual data. A higher percentage indicates that the model is more accurate. Final prediction error FPE is a measure of the overall accuracy of the model. It is a statistical measure that considers both the model's ability to fit the data and its ability to make predictions. A lower FPE value indicates that the model is more accurate. Mean square error MSE is a measure of the average difference between the model's predictions and the actual data. It is a commonly used measure of model accuracy, with lower values indicating better performance. Table 4 tabulates the status of ARX and ARMAX model while Figure 8 shows the step prediction response of ARX and ARMAX model in this paper.

Table 4: Status of ARX and ARMAX Model

Order	FPE	MSE	Best Fit (%)
ARX 661	0.002083	0.002046	82.49
ARMAX 8881	0.001844	0.001786	96.50

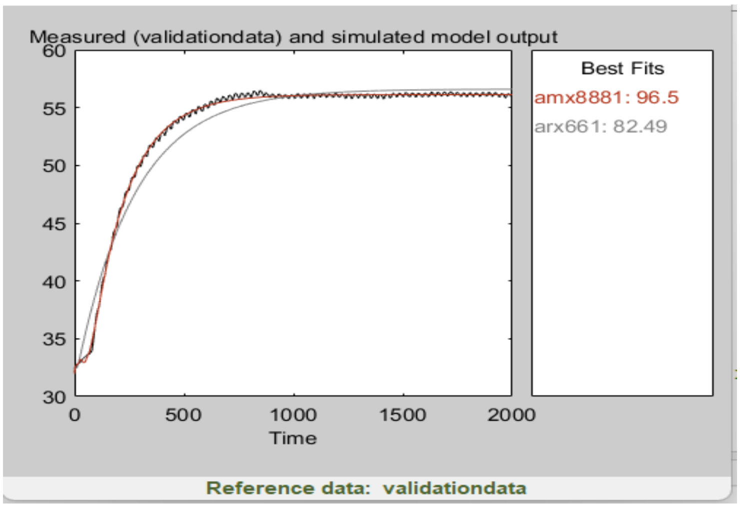

Figure 8: Step prediction response of ARX and ARMAX model.

The greater the percentage, the better the fit to estimate data, which is in ARX order sixth model with 82.49% best fit, while in ARMAX order eighth model with 96.50% best fit as can be seen in Table 4. According to Akaike's theory, the lower the value of FPE, which is near to zero, the more accurate the model. The difference between the predicted and observed parameters, which indicates that the average set of mistakes and the final error are superior, reflects the model's overall accuracy. The results reveal that the greater the model order, the lower the value of MSE to assess model accuracy, with lower values representing better performance and FPE being appropriate for constructing the herb drying controller. As can be seen, the eighth order ARMAX model meets the controller requirement**.**

The graph's line bandwidth shown in Figure 9 represents the amount of noise in the model. A narrower line bandwidth indicates that the model has less noise, which is desirable because it means that the model can better capture the system's underlying dynamics. A wider line bandwidth indicates that the ARX model has more noise, which is undesirable because it indicates that the model is less accurate than the ARMAX model, which has a narrower line bandwidth. This is because a low-noise model will be more accurate in predicting system behaviours, which is important for designing controllers that can effectively regulate the system.

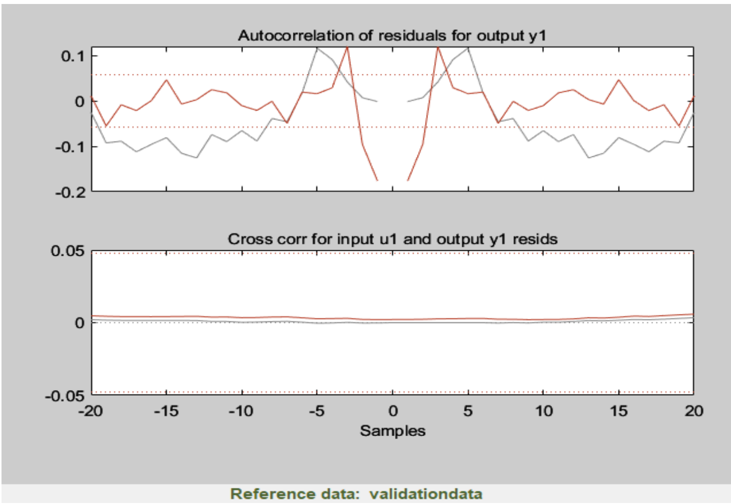

Figure 9: Noise in the model.

4. Conclusion

In conclusion, the use of linear system identification in modeling and analyzing the herb drying heating process has potential. However, it is important to be aware of its limitations such as non-linearity, dynamic behavior, measurement noise, and uncertainty, which can affect the accuracy of the model. The model created should take these factors into consideration to manage and improve the drying process. The features and the model used may vary depending on the specific application.

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