Characteristics Modeling of Optical Properties (Absorption, Reflectance, Transmittance) on Barium Titanate Using ARIMA and VARIMA

Lili Hariningrum, Muhammad Nur Aidi, I Made Sumertajaya, Irzaman

Abstract— Barium Titanate is one of the materials that can be used as a compiler of capacitors because it has a good dielectric properties. Barium titanate is then formed into a ferroelectric thin layer which will be used in measuring the relative amount of light using the spectrophotometer UV-VIS. The spectrophotometer works by measuring the relative amount of light from the largest wavelength to the smallest wavelength. This study aims to compare and determine the best model between ARIMA as univariate models and VARIMA as multivariate models for each absorption variable, reflectance, and transmittance. Based on the results of the model evaluation by looking at the smallest MAPE value it shows that the best model for the absorption variable is VARIMA (1,1,0), the best model for reflectance variables is VARIMA (1,1,0), and the best model for the transmittance variable is VARIMA (1,1,0).

Index Terms— Barium Titanate, absorption, reflectance, transmittance, modeling, ARIMA, VARIMA.

1 Introduction

Barium titanate is one material that can be used as a compiler of capacitors that has a high dielectric constant. Capacitors are one of the components of electronic equipment that have the properties of storing energy / electric charge and have many uses including avoiding the occurrence of electric jumps in circuits containing coils. Barium titanate with a tetragonal perovskite crystal structure is easily applied on the grounds that barium titanate has more stable chemical and mechanical properties (Istiqomah et al 2014). Compared to other dielectric materials, the dielectric constant of barium titanate is very high and also has several other advantages, which are stable at room temperature, non-toxic, and low Curie temperature (Deshpande et al 2005). This barium titanate is then formed into a ferroelectric thin layer which will be used in measuring the relative amount of light using the oceanoptics UV-VIS spectrophotometer (Aidi et al 2018).

UV-VIS spectrophotometer is used to see the optical properties of the material, the light source used is the visible light source, when light is passed on the material, a portion of this light will be reflected, some will be absorbed and some will be transmitted. Spectrophotometer works by measuring the relative amount of light from different wavelengths absorbed, reflected, and transmitted by a compound, where wavelengths are measured sequentially from the largest wavelength to the smallest wavelength. Observation series on these measurements resulted in the occurrence of self correlation between observations and on these measurements there is a relation with each other between the results of absorption, reflectance, and transmittance so these data can be modeled through the Autoregressive Integrated Moving Average (ARIMA) and Vector Autoreggressive Integrated Moving Average (VARIMA).

The ARIMA and VARIMA method is one of the prediction methods used to analyze an observation series, where the analysis carried out focuses on the study of behavior from previous observations which implicitly assumed that the behavior in certain observations will repeat in the next observation. According to Makridakis et al (1998) the ARIMA is a prediction method using a series of data on previous observations that are used to observe an event or a variable in that data. This method was introduced by George Box and Gwilym Jenkins for periodic analysis. ARIMA is formed from three methods, which are AR (Autoregressive), MA (Moving Average), and ARMA (Autoregressive and Moving Average). ARIMA model is carried out with three stages of modeling strategy, that are identification, estimation, and testing. The advantages of the ARIMA method is can be used for all data patterns of the observation series. The general form ARIMA (p, d, q) is stated as follows (Wei 2006):

$$\phi_p(B)(1 - B)^d Z_t = \theta_q(B)e_t$$

with $(1 - B)^d$ is differencing to d and B is the operator backshift $Z_t = Z_{t-1}$.

The VARMA method is an extension of the Auto-regressive Moving Average (ARMA) method. VARMA is a model that explains the interrelationship between observations of certain variables on an observation with observations of the variable itself on previous observa-tions. The VARMA model through differencing pro-cesses is expressed as a VARIMA model. The VARIMA model is an analysis method that involves multivariate observation series whereas the ARIMA model is a method used to analyze univariate observation series. Model VARIMA order p, d and q is formulated as fol-lows (Wei 2006):

$$\boldsymbol{\Phi}_p(B)\boldsymbol{D}(B)\boldsymbol{Z}_t = \boldsymbol{\Theta}_p(B)\boldsymbol{e}_t$$

with

$$\boldsymbol{\Phi}_p(B) = \boldsymbol{\Phi}_0 - \boldsymbol{\Phi}_1 B - \boldsymbol{\Phi}_2 B^2 - \dots - \boldsymbol{\Phi}_p B^p$$

- *Lili Hariningrum is currently pursuing master degree program in applied statistics in Bogor Agriculture University, Indonesia, PH +6281291026334. E-mail: lili.hariningruum@gmail.com*
- *Muhammad Nur Aidi is is Lecturer, Department of Statistics, Bogor Agriculture University, Bogor, Indonesia.*
- *I Made Sumertajaya is Lecturer, Department of Statistics, Bogor Agriculture University, Bogor, Indonesia.*

ISSN 2229-5518

$$\Theta_q(B) = \Theta_0 - \Theta_1 B - \Theta_2 B^2 \ldots - \Theta_q B^q$$

with Φ_p and Θ_q is a nonsingular matrix of m x m size, assuming $\Phi_p = \Theta_q = 1$.

Based on this, the author tries to examine Modeling ARIMA for each absorption, reflectance, and transmittance variables and VARIMA modeling for the third vector variable containing absorption, reflectance, and transmittance, where the two models will be evaluated in estimating the best model for each absorption variable, reflectance, and transmittance.

2 Research Method

2.1 Data

The data used in this study is a secondary data. Data is obtained through a physics experiment conducted by a team from the Dept. Physics IPB by measuring the absorption, reflectance, and transmittance levels of barium titanate films ($BaTiO_3$) using the oceanoptics UV-VIS spectrophotometer with a wavelength of 480 nm to 800 nm. There are 942 observations from this data.

2.2 Analysis Method

The stages of analysis in this research are as follows:

1. Exploring data to provide an overview of the initial data.
2. Perform stationary checks on data through the Augmented Dickey-Fuller (ADF) test . If the data is not stationary, differencing will be done.
3. Divide the data into two parts, training and testing data.
4. Form the ARIMA Model
   a. Identify ACF and PACF.
   b. Select the best model and estimate the model parameters
   c. Model goodness of fit test
5. Form the VARIMA Model
   a. Identify the VARIMA model based on the order of the model that obtained the smallest AICC value.
   b. Estimate the parameter using the least squares method.
   c. Model goodness of fit test by testing whether the residual is white noise.
6. Select the best model by evaluating the ARIMA model and the VARIMA model that has been obtained by looking at the smallest MAPE value.

3 Result and Discussion

3.1 Data Exploration

In the exploration of this data a plot will be carried out on each response obtained based on measurements of the optical properties of barium titanate, which are absorption, reflectance, and transmittance.

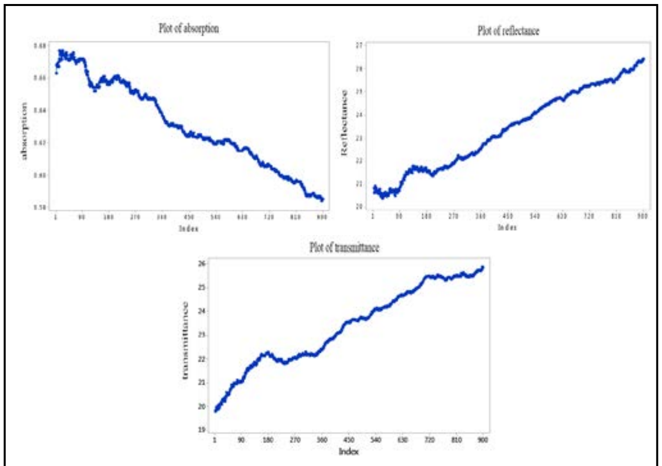

Fig. 1. Plot data on percentage absorption values, reflectance, and transmittance in barium titanate.

Exploratively, it can be seen in Figure 1 that the percentage absorption, reflectance, and transmittance values of barium titanate are fluctuating and having a pattern that is almost the same except the pattern of absorption is inversely proportional to the reflectance and transmittance patterns. Data percentage of reflectance and transmittance are uptrend, while the absorption is downtrend.

3.2 Stationary Test

In the previous discussion it was known that the percentage value of absorption, reflectance, and transmittance in barium titanate are uptrend or downtrend . This shows that the data is not stationary to the average so it needs to be differentiated. After differencing, a plot that tends to be in a zero value indicates that the data is stationary in the average and exploratively can be seen in Figure 2 that the absorption percentage, reflectance, and transmittance data on barium titanate tend to be stationary in variety.

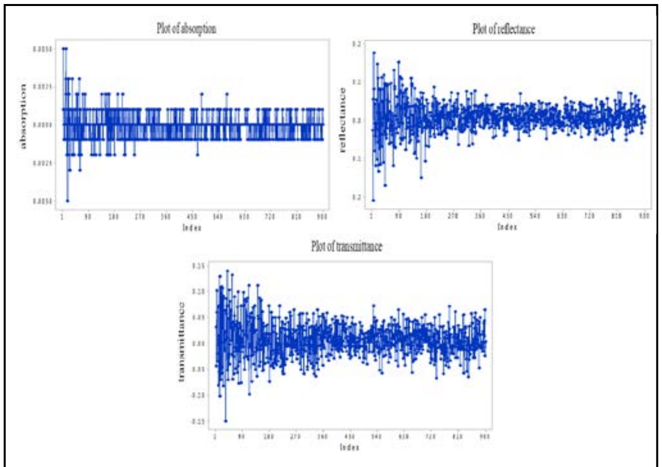

Fig. 2. Plot data on percentage absorption values, reflectance, and transmittance of barium titanate after differencing

3.3 The ARIMA Model

The process of setting up the ARIMA model is usually performed by observing the function of self correlation (ACF) and the function of its partial self correlation (PACF). Based on the ACF and PACF plots, several model candidates were obtained. The model that will be used is a model that has the smallest error value. The results of the optimum model for absorption, reflectance, and transmittance are ARIMA (0,1,1) , ARIMA (2,2,0) and ARIMA (1,1,4). The next step is to estimate the parameters of the ARIMA model using the least squares method. This method is performed by minimizing the component in the error. The estimation results of the parameters of each model are as follows:

TABLE 1
PARAMETERS ESTIMATION OF ARIMA MODEL

Variable	ARIMA Model (p,d,q)	Parameter	Coefficient of Parameters	p-value
Absorption	ARIMA (0,1,1)	θ_1	0.1435	0.000*
Reflectance	ARIMA (2,2,0)	ϕ_1	-0.5843	0.000*
		ϕ_2	-0.2941	0.000*
Transmittance	ARIMA (1,1,4)	ϕ_1	-0.3521	0.107
		θ_1	-0.2837	0.193
		θ_2	0.1383	0.000*
		θ_3	0.1073	0.009*
		θ_4	-0.1044	0.012*

Information (*) is parameters that are real at the test level of 5%.

3.4 The VARIMA Model

Identification of the VARIMA model is performed to determine the order in the formation of the VARIMA model which can be known through MACF and MPACF plots. However, this is considered subjective so that the order of determination for the VARIMA model can be performed by looking at information based on the order of the model that has the smallest AICC value. The best model obtained is the VARIMA (1,1,0). After obtaining the best VARIMA model, parameter estimation will be performed on the VARIMA (1,1,0).

TABLE 2
PARAMETERS ESTIMATION OF VARIMA MODEL

Parameter	Estimate	Standard Error	t value	p-value
$\phi_{1,11}$	-0.15484	0.03519	-4.40	0.0001*
$\phi_{1,12}$	-0.00065	0.00082	-0.80	0.4221
$\phi_{1,13}$	-0.00203	0.00087	-2.32	0.0203*
$\phi_{1,21}$	-2.47161	1.61113	-1.53	0.1254
$\phi_{1,22}$	0.03103	0.03733	0.83	0.4060
$\phi_{1,23}$	-0.02585	0.03998	-0.65	0.5181
$\phi_{1,31}$	2.90791	1.49640	1.94	0.0523
$\phi_{1,32}$	0.03395	0.03467	0.98	0.3277
$\phi_{1,33}$	-0.01615	0.03713	-0.43	0.6637

Information (*) is parameters that are real at the test level of 5%.

3.5 Best Model Selection

The formation of the ARIMA model and the VARIMA model for absorption, reflectance, and transmittance data on barium titanate has been obtained in the previous stage. The equations formed from the ARIMA model and the VARIMA model that have been obtained are presented in Table 3 and Table 4 below:

TABLE 3
EQUATION OF ARIMA MODEL

Variabel	Model	Equation
Absorption	ARIMA (0,1,1)	$Z_{1,t} = Z_{1,t-1} + e_{1,t} - 0.1435e_{1,t-1}$
Reflectance	ARIMA (2,2,0)	$Z_{2,t} = 1.4157Z_{2,t-1} - 0.1255Z_{2,t-2} + 0.0039Z_{2,t-3} - 0.2941Z_{2,t-4} + e_{2,t}$
Transmittance	ARIMA (1,1,4)	$Z_{3,t} = 0.6479Z_{3,t-1} + 0.3521Z_{3,t-2} + e_{3,t} + 0.2837e_{3,t-1} - 0.1383e_{3,t-2} - 0.1073e_{3,t-3} + 0.1044e_{3,t-4}$

TABLE 4
EQUATION OF VARIMA (1,1,0) MODEL

Variabel	Equation
Absorption	$Z_{1,t} = 0.84516Z_{1,t-1} + 0.15484Z_{1,t-2} - 0.00065Z_{2,t-1} + 0.00065Z_{2,t-2} - 0.00203Z_{3,t-1} + 0.00203Z_{3,t-2} + e_{1,t}$
Reflectance	$Z_{2,t} = -1.47161Z_{1,t-1} + 2.47161Z_{1,t-2} + 0.03103Z_{2,t-1} - 0.03103Z_{2,t-2} - 0.02585Z_{3,t-1} + 0.02585Z_{3,t-2} + e_{2,t}$
Transmittance	$Z_{3,t} = 3.90791Z_{1,t-1} - 2.90791Z_{1,t-2} + 0.03395Z_{2,t-1} - 0.03395Z_{2,t-2} - 0.01615Z_{3,t-1} + 0.01615Z_{3,t-2} + e_{3,t}$

Based on the models that have been formed in Tables 3 and Table 4, the best models will be determined for each variable. Determination of the best model can be known through the smallest forecasting error. One method used to determine the accuracy of forecasting is based on the smallest MAPE value. The best model with the smallest MAPE value of the testing data for the absorption variable is VARIMA (1,1,0) which is equal to 0.0818%, while the best model for the reflectance variable is VARIMA (1,1,0) with the MAPE value of 0.0926%, and the best model for the transmittance variable is VARIMA (1,1,0) with the MAPE value of 0.0804%.

The estimation results from the models formed in each variable are compared with the actual values presented in a plot as follows:

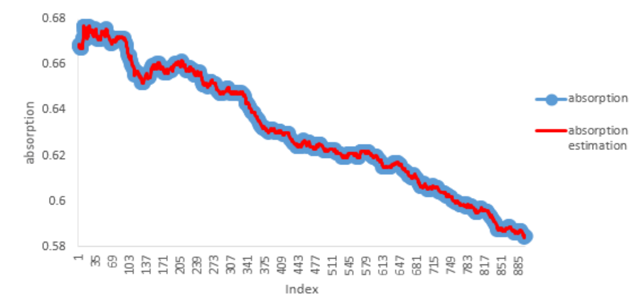

Fig. 3. Plots of Actual Data with estimated data for absorption variables in VARIMA (1,1,0)

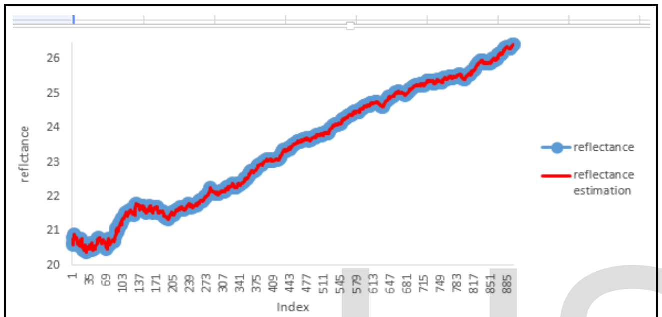

Fig. 4. Plots of Actual Data with estimated data for reflectance variables in VARIMA (1,1,0)

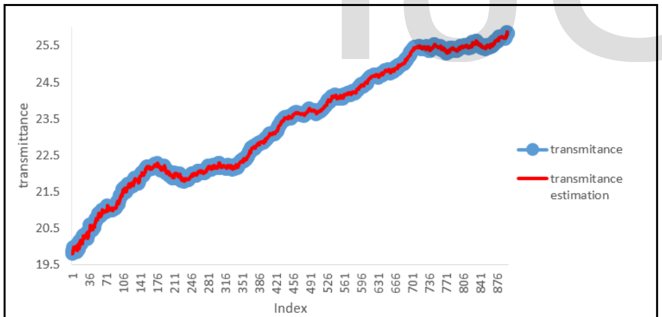

Fig. 5. Plots of Actual Data with estimated data for transmittance variables in ARIMA (1,1,0)

Based on the three plots above, it can be seen that the pattern of the predicted data follows the pattern of the actual data which means that the model obtained is good enough. This is also proven by the very small value of MAPE and the large R^2 value in each estimate, namely R^2 for the absorption variable is 99.91%, R^2 for the reflectance variable is 99.96%, and R^2 for the transmittance variable is 99.96%

4 Conclusion

Based on the research objectives, it can be concluded that the ARIMA model obtained in the formation of the ARIMA model on the absorption, reflectance, and transmittance variables is ARIMA (0,1,1), ARIMA (2,2,0), and ARIMA (1,1,4) while the VARIMA (1,1,0) is a multivariate model formed from the three variables. The model that has been obtained in each variable is then compared and selected the best model for each variable. The best model for the absorption variable is the VARIMA (1,1,0) which has a smaller MAPE value than the ARIMA (0,1,1) which is 0.0818%. The best model for reflectance variables is the VARIMA (1,1,0) which has a MAPE value that is smaller than the ARIMA (2,2,0) which is 0.0926%. And the best model for the transmittance variable is the VARIMA (1,1,0) which has a MAPE value smaller than the ARIMA (1,1,4), which is 0.0804%.

References

[1] M. N. Aidi, B. Susetyo, H. Hardhienata, Irzaman, "Regression and Arima Residual Have High Accuracy to Estimate Percent Adsorption Spectral Based on Wavelength at Barium Titanate," *International Journal of Scientific Research,* vol. 4, no. 9, pp. 585-602, 2018.

[2] S. B. Deshpande, P. D. Godbole, Y. B. Khollam, H. S. Potdar, "Characterization of Barium Titanate: BaTiO3 (BT) ceramics prepared from Sol-Gel derived BT powders," *Journal of Electroceramics*, pp. 103-108, 2005.

[3] M. Istiqomah, A. Jamaluddin, Y. Iriani, "Pembuatan Material Feroelektrik Barium Titanat ($BaTiO_3$) Menggunakan Metode Solid State Reaction," *Jurnal Fisika Indonesia*, vol. 18, no. 53, pp. 59-61, 2014.

[4] Makridakis, *Metode dan aplikasi peramalan*. Edisi 2, Jakarta : Binarupa Aksara, 1999.

[5] W. W. S. Wei, *Time Series Analysis : Univariate and Multivariate Methods Second Edition*. New York : Addison Wesley Publishing Company, Inc, 2006.