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# ALGORITHM FOR VERIFICATION OF ONLINE IDENTIFICATION OF TECHNOLOGICAL PLANTS BASED ON SENSITIVITY THEORY

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**Annotatsiya.** This article develops an algorithm for verifying the current identification of technological objects based on sensitivity theory. The proposed approach is aimed at determining the dynamic characteristics of the plant, taking into account the change in parameters over time. The use of sensitivity functions in the algorithm enhances the accuracy of model parameter estimation and ensures the stability of the identification process. The effectiveness of the developed algorithm is theoretically and practically substantiated, and it has been shown that it can also be used in non-stationary technological processes.

**Keywords:** adaptation, algorithm, identification, synthesis, minimization, sensitivity function.

**Annotatsiya.** Ushbu maqolada texnologik obyektlarni sezgirlik nazariyasi asosida joriy identifikatsiyalashni tekshirish algoritmi ishlab chiqilgan. Taklif etilgan yondashuv parametrlarning vaqt bo‘yicha o‘zgarishini hisobga olgan holda obyektning dinamik xususiyatlarini aniqlashga qaratilgan. Algoritmda sezgirlik funksiyalaridan foydalanish orqali model parametrlarini baholash aniqligi oshiriladi hamda identifikatsiya jarayonining barqarorligi ta’minlanadi. Ishlab chiqilgan algoritmning samaradorligi nazariy va amaliy jihatdan asoslangan bo‘lib,



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u nostatsionar texnologik jarayonlarda ham qo‘llanishi mumkinligi ko‘rsatib berilgan.

**Kalit so‘zlar:** adaptatsiya, algoritm, identifikatsiya, sintez, minimallashtirish, sezgirlik funksiyasi.

**Аннотация.** В данной статье разработан алгоритм проверки текущей идентификации технологических объектов на основе теории чувствительности. Предложенный подход направлен на определение динамических характеристик объекта с учётом изменения параметров во времени. Использование функций чувствительности в алгоритме позволяет повысить точность оценки параметров модели и обеспечить устойчивость процесса идентификации. Эффективность разработанного алгоритма обоснована теоретически и практически, а также показана возможность его применения в нестационарных технологических процессах.

**Ключевые слова:** адаптация, алгоритм, идентификация, синтез, минимизация, функция чувствительность.

## INTRODUCTION.

At present, ensuring high accuracy and stability in the automation of industrial technological processes is one of the most important tasks. In many cases, technological processes are characterized as nonstationary, multivariable, and sensitive dynamic systems affected by external disturbances[1,2]. This significantly complicates the identification of their parameters and real-time control.

Traditional identification methods are often based on the static or slowly varying characteristics of the plant and cannot provide sufficient accuracy under nonstationary conditions[3,4]. Therefore, the development of current (online) identification methods and their integration into adaptive control systems is considered highly relevant.

Approaches based on sensitivity theory make it possible to rapidly detect and evaluate parameter variations during the identification process[5,6,7]. Using these methods, the sensitivity of the system output with respect to parameters is analyzed, enabling real-time estimation and continuous updating of model parameters[8,9,10]. This, in turn, helps maintain and improve control performance even under nonstationary conditions.

The proposed algorithm ensures high speed and sufficient accuracy in determining dynamic parameters and contributes to the improvement of adaptive control systems.

**MATERIALS AND METHODS.** For this purpose, to evaluate the parameters of the control system, the relationship between the plant state vector $x$



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and the plant parameter vector $\alpha$ was described using the following functional dependence:

$$x(t) = F(t,\alpha) \qquad (1)$$

It is also assumed that $x(t)$, as well as the sensitivity matrix $x_\alpha = \partial F/\partial\alpha$, and the nominal (baseline) value of the parameter vector $\alpha = \alpha^0$ are known. In this case, relation (1) can be expressed in the following form:

$$x(t) = F(t,\alpha^0 + \Delta\alpha) = F(t,\alpha^0) + x_\alpha(t,\alpha^0)\Delta\alpha \text{ yoki } \Delta x(t) = x_\alpha(t,\alpha^0)\Delta\alpha \qquad (2)$$

here $\Delta x(t) = x(t) - F(t,\alpha^0)$.

Expression (2) serves as the initial formulation for determining the parameters $\alpha$. Based on this, in order to minimize the mismatch (additional variation) $\Delta x(t)$, the following algebraic relation is formed:

$$\Psi_1(x_\alpha,\Delta x)\Delta\alpha = \Psi_2(x_\alpha,\Delta x). \qquad (3)$$

From this, the variation of the parameters is determined by the following formula:

$$\Delta\alpha = \Psi_1^{-1}\Psi_2 \qquad (4)$$

Here, the operator $\Psi_1^{-1}$ is the inverse operator of $\Psi_1$.

The dynamics of the control system can be written in the form of a system of matrix equations as follows:

$$\begin{cases} \dfrac{dX}{dt} = F(X,t,\alpha), \\ Y = H\cdot X, \\ X(t_0) = X_0 \end{cases} \qquad (5)$$

Here $\alpha = [\alpha_1(t),...,\alpha_m(t)]^T$ — vector of control system parameters;

$X = [x_1(t,\alpha),...,x_n(t,\alpha)]^T$ — vector of control system state variables;

$\dfrac{dX}{dt} = \left[\dfrac{dx_1(t,\alpha)}{dt},...,\dfrac{dx_n(t,\alpha)}{dt}\right]^T$ — vector of first-order time derivatives of the control system state variables with respect to time *t*;

$F(X,t,\alpha) = \begin{bmatrix} f_1(x_1(t,\alpha),...,x_n(t,\alpha),t,\alpha_1(t),...,\alpha_m(t)) \\ \vdots \\ f_n(x_1(t,\alpha),...,x_n(t,\alpha),t,\alpha_1(t),...,\alpha_m(t)) \end{bmatrix}$ — vector of right-hand sides of the differential equations in Cauchy form;

$X_0 = [x_1(t_0,\alpha),...,x_n(t_0,\alpha)]^T$ — vector of control system state variables at the initial time moment *to*; $Y = [y_1(t,\alpha),...,y_s(t,\alpha)]^T$ — vector of control system outputs;

$H = \begin{bmatrix} h_{11}(t) & \cdots & h_{1n}(t) \\ \vdots & \ddots & \vdots \\ h_{s1}(t) & \cdots & h_{sn}(t) \end{bmatrix}$ — observability matrix, $s \le n$.



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The solution of the system of equations consists in finding the reference solution $X(t,\alpha_0)$, where $\alpha_0=[\alpha_1(t_0),...,\alpha_m(t_0)]^T$ is the vector of identifiable parameters of the control plant at the initial time moment $t_0$.

To estimate the identifiable parameters of the control system based on sensitivity theory, a system of sensitivity equations is solved.

$$\begin{cases}\dfrac{dU_k}{dt}=\beta\cdot U_k+c_k,\\ U_k(t_0)=\dfrac{dX_0}{d\alpha_k}-F(X_0,t_0,\alpha)\cdot\dfrac{dt_0}{d\alpha_k},k=\overline{1,m}\end{cases} \quad (6)$$

Here $\beta=\left[\begin{matrix}\frac{\partial f_1(x_1(t,\alpha),...,x_n(t,\alpha),t,\alpha_1(t),...,\alpha_m(t))}{\partial x_1(t,\alpha)} & \cdots & \frac{\partial f_1(x_1(t,\alpha),...,x_n(t,\alpha),t,\alpha_1(t),...,\alpha_m(t))}{\partial x_n(t,\alpha)}\\ \vdots & \ddots & \vdots\\ \frac{\partial f_n(x_1(t,\alpha),...,x_n(t,\alpha),t,\alpha_1(t),...,\alpha_m(t))}{\partial x_1(t,\alpha)} & \cdots & \frac{\partial f_n(x_1(t,\alpha),...,x_n(t,\alpha),t,\alpha_1(t),...,\alpha_m(t))}{\partial x_n(t,\alpha)}\end{matrix}\right]\Bigg|_{\alpha=\alpha_0}$ - at $\Delta\alpha=0$, a square matrix is formed from the partial derivatives of the elements of the vector $F(X,t,\alpha)$ with respect to the control system state variables (the elements of the vector **X**); $c_k=\left[\begin{matrix}\frac{\partial f_1(x_1(t,\alpha),...,x_n(t,\alpha),t,\alpha_1(t),...,\alpha_m(t))}{\partial\alpha_k(t,\alpha)}\\ \vdots\\ \frac{\partial f_1(x_1(t,\alpha),...,x_n(t,\alpha),t,\alpha_1(t),...,\alpha_m(t))}{\partial\alpha_k(t,\alpha)}\end{matrix}\right]\Bigg|_{\alpha=\alpha_0}$ — at $\Delta\alpha=0$, the vector composed of the partial derivatives of the elements of the vector $F(X,t,\alpha)$ with respect to the *k*-th nonstationary parameter of the control system (i.e., the elements of the vector $\alpha$); $U_k=\left[\frac{\partial x_1(t,\alpha)}{\partial\alpha_k(t)},\cdots,\frac{\partial x_n(t,\alpha)}{\partial\alpha_k(t)}\right]^T\Bigg|_{\alpha=\alpha_0}$ —at $\Delta\alpha=0$, the vector of partial derivatives of the elements of the vector **X** with respect to the *k*-th identifiable parameter of the control system; $\frac{dU_k}{dt}=\left[\frac{d}{dt}\left(\frac{\partial x_1(t,\alpha)}{\partial\alpha_k(t)}\right),\cdots,\frac{d}{dt}\left(\frac{\partial x_n(t,\alpha)}{\partial\alpha_k(t)}\right)\right]^T\Bigg|_{\alpha=\alpha_0}$ — At $\Delta\alpha=0$, $k=\overline{1,m}$, the vector of time derivatives (with respect to time *t*) of the elements of the vector $U_k$; $U_k(t_0)=0$ — the vector of sensitivity functions of the closed-loop system state variables with respect to the *k*-th identifiable parameter of the control plant at the initial time moment $t_0$ ($n\times1$, $k=\overline{1,m}$).

The sensitivity vectors $U_k$, $k=\overline{1,m}$ are the solutions of the system of sensitivity equations (6).

The system of equations (6) can be written in matrix form as follows:



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$$\begin{cases} \dfrac{dU}{dt} = \beta \cdot U + c, \\ U(t_0) = 0 \end{cases} \qquad (7)$$

Here: $c = \left[ \begin{matrix} \dfrac{\partial f_1(x_1(t,\alpha),...,x_n(t,\alpha),t,\alpha_1(t),...,\alpha_m(t))}{\partial \alpha_1(t,\alpha)} & \cdots & \dfrac{\partial f_1(x_1(t,\alpha),...,x_n(t,\alpha),t,\alpha_1(t),...,\alpha_m(t))}{\partial \alpha_m(t,\alpha)} \\ \vdots & \ddots & \vdots \\ \dfrac{\partial f_n(x_1(t,\alpha),...,x_n(t,\alpha),t,\alpha_1(t),...,\alpha_m(t))}{\partial \alpha_1(t,\alpha)} & \cdots & \dfrac{\partial f_n(x_1(t,\alpha),...,x_n(t,\alpha),t,\alpha_1(t),...,\alpha_m(t))}{\partial \alpha_m(t,\alpha)} \end{matrix} \right]_{\alpha=\alpha_0}$ -

at $\Delta\alpha = 0$, the matrix of partial derivatives of the elements of the vector $F(X,t,\alpha)$ with respect to the identifiable parameters of the control system;

$U = \left[ \begin{matrix} \dfrac{\partial x_1(t,\alpha)}{\partial \alpha_1(t)} & \cdots & \dfrac{\partial x_1(t,\alpha)}{\partial \alpha_m(t)} \\ \vdots & \ddots & \vdots \\ \dfrac{\partial x_n(t,\alpha)}{\partial \alpha_1(t)} & \cdots & \dfrac{\partial x_n(t,\alpha)}{\partial \alpha_m(t)} \end{matrix} \right]_{\alpha=\alpha_0}$ — at $\Delta\alpha = 0$, the sensitivity matrix of the state variables with respect to the identifiable parameters of the control system;

$\dfrac{dU}{dt} = \left[ \begin{matrix} \dfrac{d}{dt}\left(\dfrac{\partial x_1(t,\alpha)}{\partial \alpha_1(t)}\right) & \cdots & \dfrac{d}{dt}\left(\dfrac{\partial x_1(t,\alpha)}{\partial \alpha_m(t)}\right) \\ \vdots & \ddots & \vdots \\ \dfrac{d}{dt}\left(\dfrac{\partial x_n(t,\alpha)}{\partial \alpha_1(t)}\right) & \cdots & \dfrac{d}{dt}\left(\dfrac{\partial x_n(t,\alpha)}{\partial \alpha_m(t)}\right) \end{matrix} \right]_{\alpha=\alpha_0}$ — at $\Delta\alpha = 0$, the matrix of time derivatives (with respect to time *t*) of the elements of the sensitivity matrix; $U(t_0) = 0$ — at the time instant $t_0$, the zero matrix ($n \times m$) of sensitivity functions of the state variables with respect to the identifiable parameters.

For given values of $X(t,\alpha_0)$, U, and small $\Delta\alpha$, the following relation holds:

$$X(t,\alpha_0 + \Delta\alpha) = X(t,\alpha_0) + U \cdot \Delta\alpha \qquad (8)$$

Expression (5) shows that the problem of identifying the parameters of the control system consists in determining an estimate of the vector $\alpha$ based on measurements of the vector **Y**. The difference between the measured and the identified values should tend to a minimum. For this purpose, the following criterion is introduced:

$$I = \int_0^T \left\| Y_{o'lch} - Y \right\| \to \min, \qquad (9)$$

Here, $Y_{o'lch}$ — is the vector of measured outputs of the control system.

The vector **Y** is determined taking into account expression (8).

$$Y = H \cdot X(t,\alpha_0 + \Delta\alpha) = H \cdot X(t,\alpha_0) + H \cdot U \cdot \Delta\alpha \qquad (10)$$

The value of $\Delta\alpha$ is determined by minimizing the functional (9):



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$$I = \int_0^T \left\| Y_{o'lch} - H \cdot X(t,\alpha_0) - H \cdot U \cdot \Delta\alpha \right\| = \\ = \int_0^T \left[ \left( Y_{o'lch} - H \cdot X(t,\alpha_0) - H \cdot U \cdot \Delta\alpha \right)^T \left( Y_{o'lch} - H \cdot X(t,\alpha_0) - H \cdot U \cdot \Delta\alpha \right) \right] dt \quad (11)$$

By introducing these notations, the following expression for $\Delta Y = Y_{o'lch} - H \cdot X(t,\alpha_0), \quad G = H \cdot U$ is obtained:

$$I = \int_0^T \left[ \left( \Delta Y - G \cdot \Delta\alpha \right)^T \left( \Delta Y - G \cdot \Delta\alpha \right) \right] dt \quad (12)$$

By transforming expression (12), the following expression is obtained:

$$I = \int_0^T \left[ \Delta Y^T \Delta Y - 2\Delta\alpha^T G^T \Delta Y + \Delta\alpha^T G^T G \cdot \Delta\alpha \right] dt \quad (13)$$

By differentiating equation (13) with respect to $\Delta\alpha$, the necessary condition for achieving the minimum of **I** is obtained as follows:

$$I = \int_0^T G^T G \cdot \Delta\alpha dt - \int_0^T G^T \Delta Y dt \quad (14)$$

$$B \cdot \Delta\alpha = C, \quad (15)$$

Here $B = \int_0^T G^T \cdot G dt, \quad C = \int_0^T G^T \cdot \Delta Y dt$.

The matrix **B** (identification matrix) is the Gram matrix of the column vectors of the matrix **G**.

Based on sensitivity theory, an algorithm has been developed for estimating the variations of the identifiable parameters of the control process.

A distinctive feature of the algorithm is that the elements of the parameter vector $\alpha$ are taken as the coefficients of the differential equation describing the dynamics of the control system.

To verify the reliability of the identification results, the Kalman observability criterion was used.

In this case, for computational purposes, it is necessary to transform the state variables into a system of first-order differential equations:

$$X_i = \Lambda X_{i-1} + \Theta u_{i-1}, \\ y_{i-1} = C X_{i-1} \quad (16)$$

Here: $X_i = \begin{bmatrix} x_{1i} \\ x_{2i} \end{bmatrix}$ — state vector, 2×1; $\Lambda = \begin{bmatrix} \lambda_{11} & \lambda_{12} \\ \lambda_{21} & \lambda_{22} \end{bmatrix}$ — dynamic (system) matrix, 2×2; $\Theta = \begin{bmatrix} \theta_1 \\ \theta_2 \end{bmatrix}$ — control matrix, 2×1; $u_{i-1}$ — control input;

$y_{i-1}$ — system output; $C = [c_1 \quad c_2]$ — output matrix, 1×2.

The vector-matrix representation of the system (16) can be written in scalar form



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(17) as follows:

$$\begin{cases} x_{1i} = \lambda_{11}x_{1i-1} + \lambda_{12}x_{2i-1} + \theta_1 u_{i-1} \\ x_{2i} = \lambda_{21}x_{1i-1} + \lambda_{22}x_{2i-1} + \theta_2 u_{i-1} \\ y_{1i-1} = c_1 x_{1i-1} + c_2 x_{2i-1} \end{cases} \quad (17)$$

After applying the time-shift operator **z**, system (16) takes the form (19):

$$\begin{cases} x_1 z^0 = \lambda_{11}x_1 z^{-1} + \lambda_{12}x_2 z^{-1} + \theta_1 u z^{-1} \\ x_2 z^0 = \lambda_{21}x_1 z^{-1} + \lambda_{22}x_2 z^{-1} + \theta_2 u z^{-1} \\ y_1 z^{-1} = c_1 x_1 z^{-1} + c_2 x_2 z^{-1} \end{cases} \quad (18)$$

By expressing $x_1$ from the first equation and $x_2$ from the second equation of system (18), and substituting them into the third equation, the relationship of the system output $y$ with respect to the control input $u$ is obtained:

$$\begin{aligned} & y \cdot (1 + (-\lambda_{22} - 2\lambda_{11}) \cdot z^{-1} + (2\lambda_{22}\lambda_{11} - \lambda_{21}\lambda_{12} + \lambda_{11}^2) \cdot z^{-2} + (\lambda_{21}\lambda_{12}\lambda_{11} - \lambda_{22}\lambda_{11}^2) \cdot z^{-3}) = \\ & = u \cdot ((c_1\theta_1 + c_2\theta_2) \cdot z^{-1} + (c_1(\lambda_{12}\theta_{22} - \lambda_{11}\theta_{11} - \lambda_{22}\theta_{11}) + c_2(\lambda_{21}\theta_{11} - 2\lambda_{11}\theta_{22})) \cdot z^{-2} + \\ & + (c_1(\lambda_{11}\lambda_{22}\theta_{11} - \lambda_{12}\lambda_{11}\theta_{22}) + c_2(-\lambda_{11}\lambda_{21}\theta_{11} + \lambda_{11}^2\theta_{22})) \cdot z^{-3}) \end{aligned} \quad (19)$$

After performing online identification, in order to verify observability, it is necessary to transform the system model representation from the regression form to the state-variable form (16).

This transformation is carried out by solving a system of equations that establishes the relationship between the model parameters in the state-variable form and those in the regression form.

$$\begin{cases} \alpha_1^{c11} = -(-\lambda_{22} - 2\lambda_{11})) \\ \alpha_2^{c11} = -(2\lambda_{22}\lambda_{11} - \lambda_{21}\lambda_{12} + \lambda_{11}^2) \\ \alpha_3^{c11} = -(\lambda_{21}\lambda_{12}\lambda_{11} - \lambda_{22}\lambda_{11}^2) \\ \beta_1^{c11} = c_1\theta_1 + c_2\theta_2 \\ \beta_2^{c11} = c_1(\lambda_{12}\theta_{22} - \lambda_{11}\theta_{11} - \lambda_{22}\theta_{11}) + c_2(\lambda_{21}\theta_{11} - 2\lambda_{11}\theta_{22}) \\ \beta_3^{c11} = c_1(\lambda_{11}\lambda_{22}\theta_{11} - \lambda_{12}\lambda_{11}\theta_{22}) + c_2(-\lambda_{11}\lambda_{21}\theta_{11} + \lambda_{11}^2\theta_{22}) \end{cases} \quad (20)$$

The reliability of the identification results is verified by substituting the parameters $\overline{\alpha^{c11}}$ and $\overline{\beta^{c11}}$, obtained from the online identification, into the system of equations and solving them with respect to the unknown elements of the matrices $\Lambda$ and **C**.

**CONCLUSION.** In this study, an algorithm for verifying methods of the current identification of technological plants based on sensitivity theory has been developed and analyzed. The use of sensitivity functions in the identification process, based on the proposed algorithm, improves the accuracy of parameter estimation, optimizes the computational process, and expands the capability of operating in real time.



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This method operates effectively even under nonstationary conditions of technological processes and contributes to the formation of reliable mathematical models for the synthesis of control systems.

## REFERENCES

1. Ibragimov B.Sh. "Mathematical description of a bleach impregnation reservoir," Chemical Technology, Control and Management: Vol. 2023: Iss. 2, Article 11. DOI: https://doi.org/10.59048/2181-1105.1451

2. Siddikov I.H., Ibragimov B.Sh., Rustamova M.B. Synthesis of an adaptive digital system for modal control of a dynamic plant Proc. SPIE 13217, Third International Conference on Digital Technologies, Optics, and Materials Science (DTIEE 2024), 1321714 (31 July 2024); https://doi.org/10.1117/12.3035648 (3, Scopus, IF= 0.189)

3. Бронников А.М. Способы реализации адаптивной системы управления с идентификатором и эталонной моделью // XII Всероссийское совещание по проблемам управления ВСПУ-2014 Москва 16-19 июня 2014 г.

4. *Азарсков В.Н., Житецкий Л.С., Соловчук К.Ю.* Параметрическая идентификация многосвязного статического объекта в замкнутом контуре управления: специальный случай // XII Всероссийское совещание по проблемам управления ВСПУ–2014, Москва, 16–19 июня 2014 года: труды. – М.: Ин-т проблем управления им. В.А. Трапезникова РАН, 2014. – С. 2764–2776

5. В.С.Кудряшов, С.В.Рязанцев, О.В.Тарабрина, Д.А.Свиридов / Исследование алгоритма текущей идентификации на основе теории чувствительности / Материалы IV междунар. науч. конф. «Современные проблемы прикладной математики, теории управления и математического моделирования» - Воронеж.-2011. —С.160.

6. Оморов Р.О. Модальная чувствительность, робастность и грубость динамических систем (обзорная статья) // Научно-технический вестник информационных технологий, механики и оптики. 2021. Т. 21, № 2. С. 179–190. doi: 10.17586/2226-1494-2021-21-2-179-190

7. Букреев, В. Г., Параев, Ю. И., Шамин, А. М., & Чащин, А. К. (2005). Алгоритм идентификации параметров электромеханического объекта на основе теории чувствительности. Известия Томского политехнического университета. Инжиниринг георесурсов, 308 (3), 143-146.

8. Siddikov I.H., Ibragimov B.Sh. "Synthesis of a control system for a non-stationary dynamic plant based on a regulator-predictor," Chemical Technology, Control and Management: Vol. 2024: Iss. 4, Article 5. DOI: https://doi.org/10.59048/2181-1105.1580 (05.00.00, №12)



ISSN 3030-3907

9. Ibragimov, B.SH., Juraev, A.K., Eshkobilov, S.B., Norboev, O.N., & Jurayev, F.D. (2023, May). Nonlinear control object identification problems: Methods and approaches. E3S Web of Conferences 392, 02043 (2023). https://doi.org/10.1051/e3sconf/202339202043, (3, Scopus, IF=0.66)
10. Isamiddin Siddikov, Davronbek Khalmatov, Gulchekhra Alimova, Ulugbek Khujanazarov, Sadikova Feruzaxon, Mustafoqul Usanov. Investigation of auto-oscillational regimes of the system by dynamic nonlinearities. International Journal of Electrical and Computer Engineering (IJECE). Vol. 14, No. 1, February 2024, pp. 230–238. DOI: 10.11591/ijece.v14i1.pp230-238



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