Dynamic Modeling of a Tremor Test Rig

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Abstract: - Debilitating conditions for patients with hand tremor may find their daily activities such as writing and holding objects affected. Thus an active tremor device could be an option to suppress hand tremor. This study presents a tremor test rig as the initial stage to develop active controller. The system identification is used to locate approximate models of tremor test rig based on observed input output data pairs. The parametric identification of the hand tremor using least square (LS) with auto-regressive exogenous input (ARX) model structure is considered. Here, five correlation tests are used to validate the obtained model. The findings verified that the dynamic model obtained is the best description to represent tremor test rig and the system show stability.

Key-Words: - Tremor test rig, System identification, Hand tremor

1 Introduction

Tremor may describe as involuntary, rhythmic or shaking movement of one or more body part at a relatively fixed frequency and amplitude [1]-[2]. The frequency of tremor regularly occurs at range 4 to 12 Hz [3]. The most commonly tremor happens at the hand. Tremor patient may suffer difficulty in doing daily activities such as holding or eating and at worst situation it may give depressed mood for the patient. There are three main types of tremor which are resting, postural and action tremor. Resting tremor happens when the muscles stay relax. Postural tremor appears when a part of the body is elevated against gravity. Meanwhile action tremor happens when a part of body moves deliberately.

Several cause of tremor has been found out for instance stress, smoking, alcohol, use of certain drugs and others [4]. Excessive alcohol consumption may kill certain nerve cell, resulting tremor especially in the hand. There is no cure for tremor but some medicine or surgical treatments can be used to slow down the tremor progress.

Another alternative way is using biomechanical loading as a technique to suppress the effect of tremor. It can be separated into active and passive device. This study intended to develop an active tremor device by initially proposed the tremor test rig that able to emulate actual hand tremor in postural condition. Bear in mind, an active device does not intend continuously suppress tremor as the device purposely in helping patient doing desire task at certain time in which it gives advantages compare to the passive one. Prior to embed an active controller into the device, the controller and system need carefully design in simulation work. Therefore, it is essential to find out the transfer function of the test rig that can represent the model of the rig. One way is to use system identification method. The major aim of system identification is to determine approximate or accurate models of dynamics systems based on observed inputs and outputs. System identification is widely use in the application to control the physical system or to predicts its behaviour under different operating condition [5].

In this research, dynamic modelling of a tremor test rig is considered using parametric model. The selected parametric model type is auto-regressive exogenous input (ARX) model structure and for estimate model using least square (LS) estimation. The findings model is test with several validation methods, and a comparative assessment of the results is presented and discussed.

2 Methodology

2.1 Experimental Rig

In this study, a fake model of hand-arm is used to simulate the hand tremor. The material used to fabricate hand model is urethane rubber and it has stiffness and feel like a real human hand. A lightweight accelerometer is employed to quantify the tremor signal. For actuation system, a bi-directional linear voice coil actuator (LVCA) is exercised to counter act the effect of tremor.

Fig. 1 shows the configuration of tremor test rig. The experimental test rig consists of several main components such as two springs, two rod bar and two holders. Shaker are assemble at the beneath of inter connector bar and its function is to excite the hand model. To hold the upper rod bar firmly, bearings are used. The bearings also help to provide smooth upwards and downwards vertical movements.

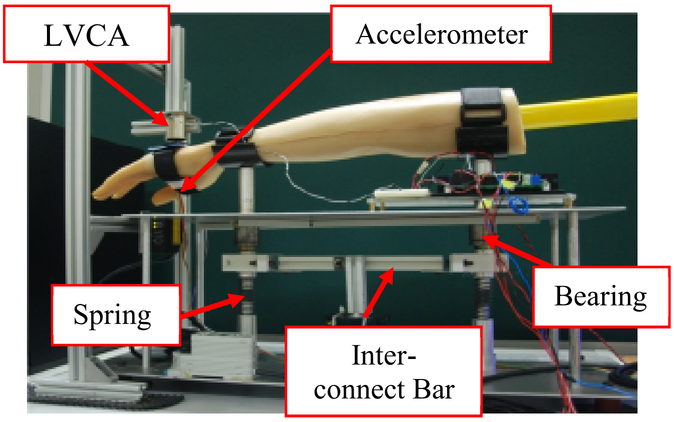

Fig. 1: Hand-arm model rig.

Springs separated the rod bars into two sections (upper and lower) and help to provide a good vertical vibration oscillation when the shaker vibrates. The hand-arm model is placed horizontally on the holders at the test rig. This represents the hand-arm vibration which resembles the hand postural. Velcro belts are used to ensure that the hand-arm model is held firmly onto the holder. This is to prevent energy losses when the hand-arm model is excited.

2.2 Experimental Setup and Data Capturing

Fig. 2 depicts an experimental environment in which the configuration of experimental setup and devices that are used. A light-weight tri-axial accelerometer; mounted at the palm that purposely to assess the dynamic response at the point. Meanwhile, the linear voice coil actuator is attached parallel to the location of the sensor for the reason of collocated control. Since the hand-arm is vibrating in vertical direction in postural tremor, the Z-axis is the primary plane of measurement on the model.

The output voltage from the accelerometer is directed connect to the analog input of Data Acquisition System (DAS) while the analog output of the DAS sent a voltage signal to the LVCA to drive the actuator. The data transferred between input and output of DAS card were recorded and displayed on the personal computer via LabVIEW software version 8.6.

Here the PRBS signal is injected to the LVCA and the dynamic response of the hand is accessed by means of accelerometer. Both input and output data were recorded for the purpose to exercise it in identification process. Prior of measurement, the band pass Butterworth filter with cut-off frequency at 2-30Hz is employed to reduce the noise signal from the accelerometer. The experimental work need to design properly in terms of noise cancellation and the right arrangement of test rig so that the output of models response is fits with the system response and hence gives small variance of error.

The analysis routine of system identification is carried out in Matlab environment. The data are then properly formatted using Microsoft Excel before finally imported to the Matlab software for further analysis. The outcome from the analysis is the transfer function that describes the tremor test rig. The time domain and frequency domain as long as the correlation tests results also were displayed.

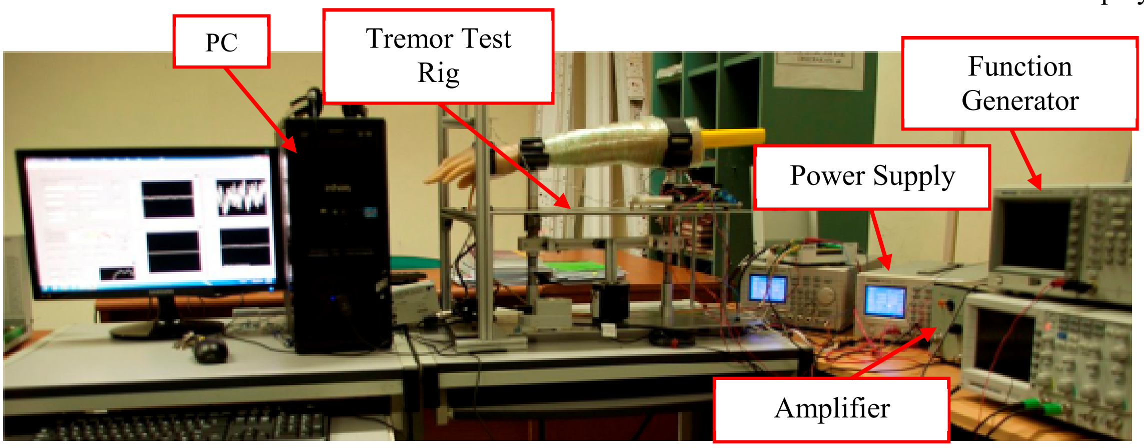

Fig. 2: The experimental setup

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3 System Identification

3.1 Parametric modeling

A parametric method can be described as a mapping from the experimental data to the estimated parameter vector. In this investigation, parametric identification of the hand tremor using least square (LS) with auto-regressive exogenous input (ARX) model structure is considered. The basic structure of the ARX model is the linear difference equation [6]:

$$y(t_i) = -a_1 y(t_{i-1}) - a_2 y(t_{i-2}).... - a_{na} y(t_{i-na}) + b_1 u(t_{i-1}) + b_2 u(t_{i-2}) + ... + b_{nb} u(t_{i-nb}) + e(t_i) \quad (1)$$

which the input signal denotes as $u(t_i)$ while output signal is $y(t_i)$ and $e(t_i)$ denoting as zero mean white noise. Equation (1) may be rewrite in discrete linear transfer function form:

$$y(t_i) = \frac{B(z^{-1})}{A(z^{-1})} u(t) + \frac{1}{A(z^{-1})} e(t_i) \quad (2)$$

where the $A(z^{-1})$ and $B(z^{-1})$ are polynomials with associated parameters of autoregressive and exogenous parts, respectively as:

$$A(z^{-1}) = 1 + a_1 z^{-1} + ... + a_{na} z^{-na} \quad (3)$$

$$B(z^{-1}) = b_1 + b_2 z^{-1} + ... + b_{nb} z^{-nb} \quad (4)$$

Fig. 3 illustrated the ARX model structure, in which the AR refers to the autoregressive part $A(z)y(t_i)$ and X to the extra input $B(z)u(t_i)$ which is called as exogenous variable in econometric.

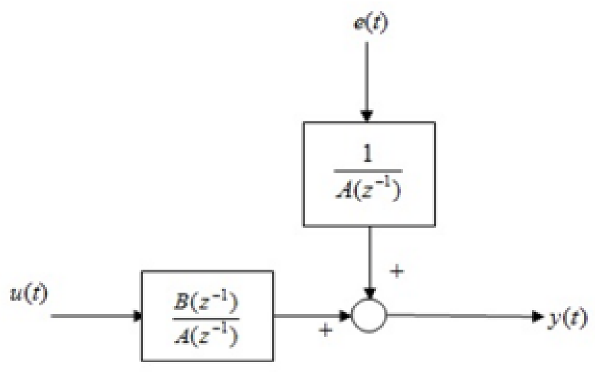


Fig. 3: Model structure of ARX

The residual or prediction error is given by

$$e(t_i) = y(t_i) - \hat{y}(t_i) \quad (6)$$

Substituting equation (6) into equation (2), thus the predicted output can be expressed in the following form

$$\hat{y}(t_i \mid x) = B(z^{-1}) u(t) + [1 - A(z^{-1})] y(t) \quad (5)$$

For more compact notation, the above predictor can be presented in discrete vector form:

$$\hat{y}(t_i) = \varphi^T(t_i) x \quad (6)$$

where, $\hat{y}(t_i \mid x)$ is the predicted output.

$$x = [a_1 .... a_n \quad b_n \; ... \; b_m]^T \in R^n \quad (7)$$

$$\varphi(t_i) = \begin{bmatrix} -y(t_{i-1}) \; ... \; -y(t_{i-na}); \\ u(t_{i-1}) \; ... \; u(t_{i-nb}) \end{bmatrix}^T \quad (8)$$

3.2 Model Estimation

In this paper, the least square (LS) estimation is considered as a deterministic approach to the estimation problem. The LS algorithm is based on the steepest descent method [7]. In least square estimation, the performance index is described as:

$$J = \sum e^2 = e^T e = (y - \varphi^T x)^T (y - \varphi^T x) \quad (9)$$

By minimizing the performance index with respect to x,

$$\frac{\partial J}{\partial x} = 0 \quad (10)$$

Thus, the least square solution for the parameter vector x is:

$$x(t_i) = (\varphi^T \varphi)^{-1} \varphi^T y(t_i) \quad (11)$$

3.3 Model Validation

Model validation is used as a tool to measure how well an obtained model to represent the system. It is a statistical test that shows the degrees of the relationship between two variables (input voltage from LVCA to acceleration signal). Equation (12) to equation (16) derives the 5 standard correlation tests that used in model validation [8].

$$\phi_{\varepsilon\varepsilon}(\tau) = E[\varepsilon(t-\tau)\varepsilon(t)] = \delta(\tau) \quad (12)$$

$$\phi_{u\varepsilon}(\tau) = E[u(t-\tau)\varepsilon(t)] = 0, \forall\tau \quad (13)$$

$$\phi_{u^2\varepsilon}(\tau) = E[(u^2(t-\tau) - \bar{u}^2(t))\varepsilon(t)] = 0, \forall\tau \quad (14)$$

$$\phi_{u^2\varepsilon^2}(\tau) = E[(u^2(t-\tau) - \bar{u}^2(t))\varepsilon^2(t)] = 0 \quad \forall\tau \quad (15)$$

$$\phi_{\varepsilon(\varepsilon u)}(\tau) = E[\varepsilon(t)\varepsilon(t-1-\tau)u(t-1-\tau)] = 0 \quad \tau \ge 0 \quad (16)$$

where, $\phi_{\varepsilon\varepsilon}(\tau)$ shows the auto-correlation of the residuals should be an impulse, and $\phi_{u\varepsilon}(\tau)$ indicates the cross-correlation function between input $u(t)$ and residuals $\varepsilon(t)$. The model of the system is suffice if the residuals errors, $\varepsilon(t)$ for all lags within 95% confident bands or $1.96/\sqrt{N}$ (where N is the data length).

4 Results and Discussions

In order for the input to be persistently exciting, a pseudo-random binary sequence (PRBS) signal was injected to excite the LVCA at the test rig. Fig. 4 shows the input signal which is the PRBS signal with a level of ±0.7V. Fig. 5 depicts the output signal which is the acceleration signal obtained from the miniature accelerometer. The system response was observed over duration of 10 seconds.

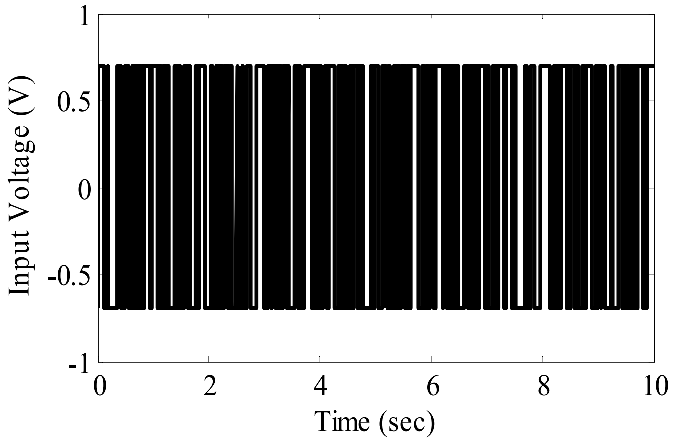


Fig. 4: PRBS input signal

For simulation purpose, the best result was achieved with model order 4 which gives smallest MSE level. Fig. 6 illustrated the poles zeros in z-plane. The system show stability as all poles lay inside the unit circle.

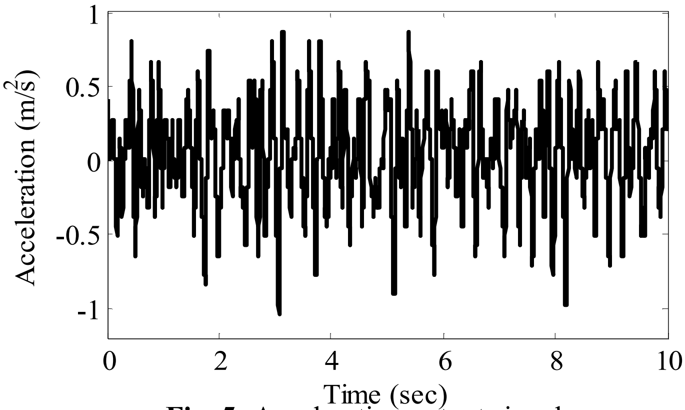


Fig. 5: Acceleration output signal

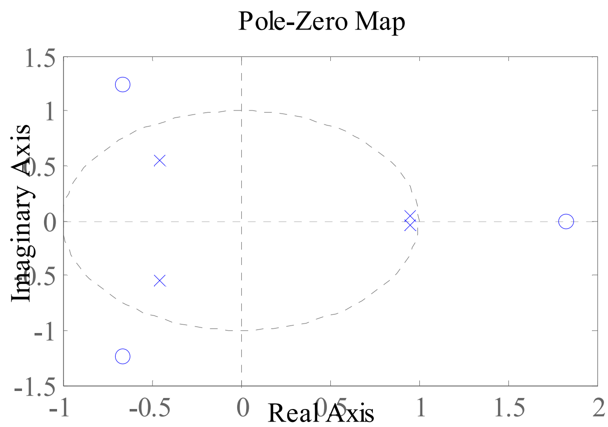
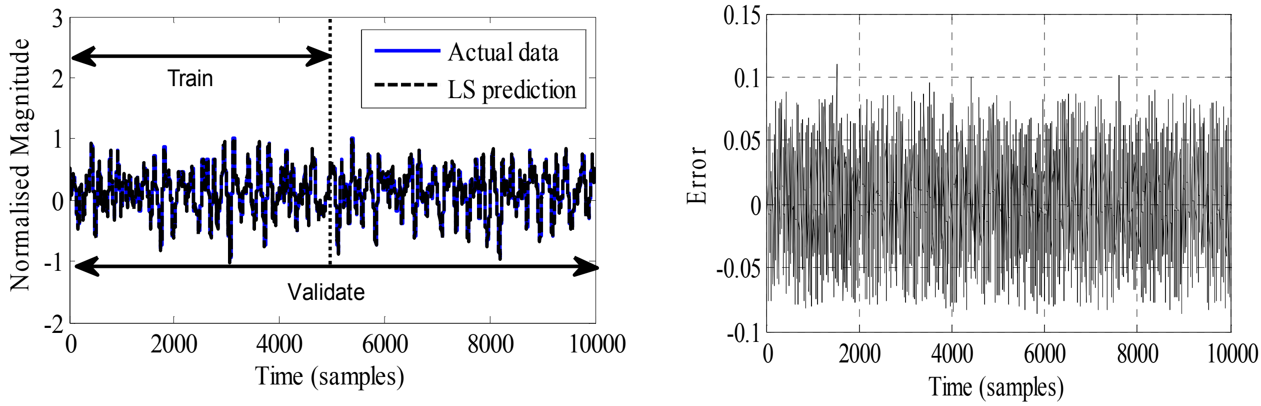


Fig. 6: Z-plane

In this study, the first 5000 data is used for train the model and the whole 10000 data is used for validation purpose including the remains 5000 data that had not been used in training process. The validation test is intended for the whole set of data so that overall prediction error could be used in the correlation test. Fig. 7(a) and 7(b) depicts the comparison between the actual data and LS predicted output in terms of its magnitude and error, respectively. As can be seen in Fig. 7(b), the error shows small variant in which the MSE level is 0.00049. The findings actually indicated that the model output fits and can be used to represent the tremor test rig. The transfer function between the input voltages of LVCA to the acceleration output of hand tremor response can be summarized as follows:

$$\frac{0.005336z^{-1} - 0.006685z^{-2} - 0.0006237z^{-3} - 0.007207z^{-4}}{1 - 0.9938z^{-1} - 0.1764z^{-2} - 0.1216z^{-3} + 0.306z^{-4}}$$

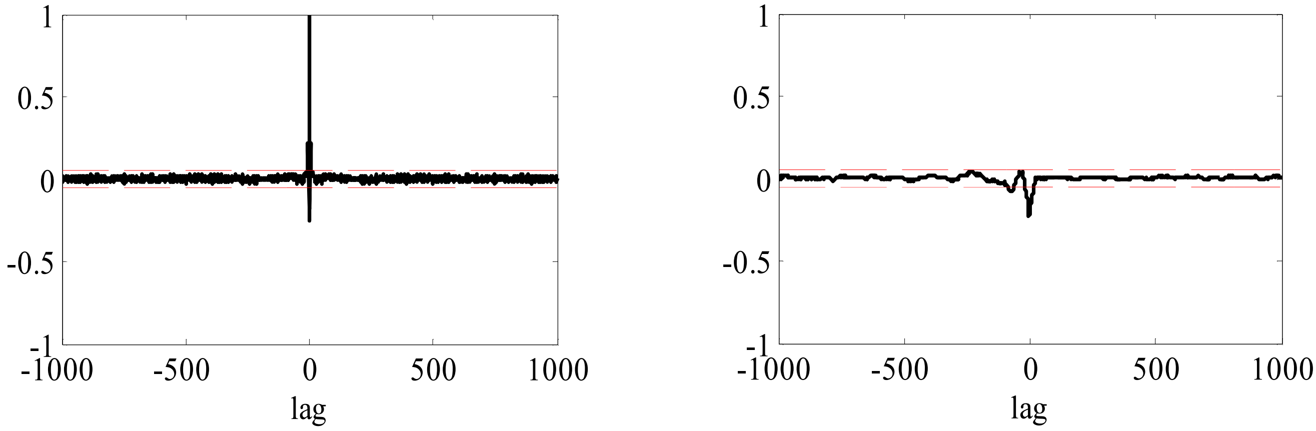
Fig. 8 shows the results of correlation test. It was noted that, all correlation tests of the tremor test rig model show that the correlation functions were within the 95% confidence interval indicating an adequate model fit.



(a) The actual and LS predicted output

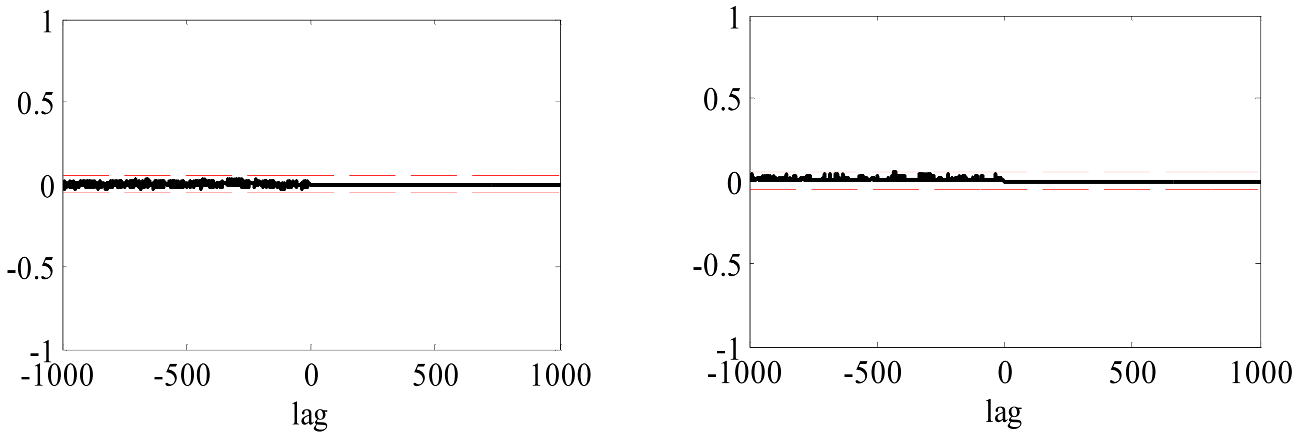
(b) Error between actual and LS predicted output

Fig. 7: Least square estimation with PRBS input



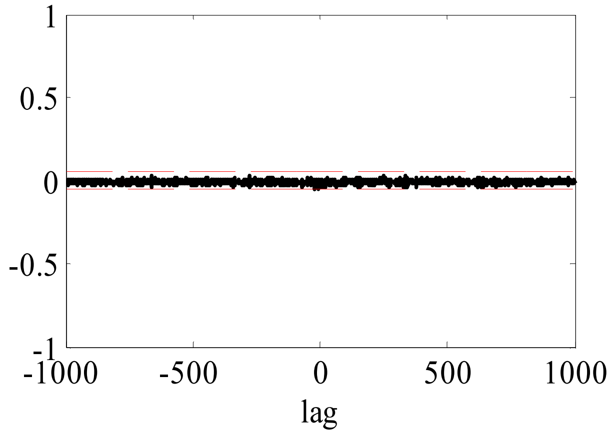
(a) Auto-correlation of residuals.

(b) Cross-correlation of inputs and residuals.



(c) Cross-correlation of input square and residuals.

(d) Cross-correlation of input square and residuals square.



(e) Cross-correlation of residuals and (input*residuals).

Fig. 8: Correlation tests of LS with PRBS input.

5 Conclusions

System identification is used to characterize the model of the tremor test rig based on the input-output data pairs. The input of the model is the PRBS signal in voltage form that excites the LVCA while the model output is the acceleration signal which indicates the tremor response at the palm. The study findings reveal that all poles are within the stable region. The small variant of error indicates that the model obtained fits with the system response. The results were found to be within 95% confidence level thus confirming its accuracy. The obtained transfer function model of the tremor test rig will provide huge benefit in simulation study particularly in the design of appropriate active controller. It will also be beneficial for future practical implementation of tremor suppressing.

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