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Identification of Flip Folder Model on Folding Machine

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Abstract. Folding Machine is an indispensable tool in the small-scale laundry industry that aims to save time and energy. The main component of this equipment is a flip folder that will be controlled in the form of deflection of the angle position in order to operate the folded clothes. In the design of the controller, what needs to be done is the identification of the plant to determine the characteristics of the system. Modelling section in this paper is using relationships between input variables; input components are often difficult to measure the parameters of the plant. Therefore, this research will identify the system based on the offline input and output data measurement by using Extended Least Square (ELS) and Auto Regressive Exogenous (ARX) model approach. Based on the results of the identification, the second order damped plant equation can be approximated by first order reduction model with the characteristic transient response that having a time constant (τ) of 0.1706 seconds, the rise time of 0.500 seconds, the settling time of 0.511 seconds and the delay time of 0.1178 seconds.

1. Introduction

Several processes of cleaning clothes that can be run by the machine are the process of washing and drying, while the process for folding clothes still using the manual way. It is necessary to apply an automated technology to be able to do this folding process. One of the automation technologies that can be applied to the process of folding is by using the automatic folding machine. This tool uses the angle position deflection control mechanism of the flip. The working principle of the fold on the folding machine resembles a robot arm manipulator 1 DOF (Degree of Freedom). Several flip pieces will be arranged in such a way that can make the process of folding clothes [1–2].

A prototype folding machine has been designed using a simple mechanism with a semi-automatic system for clothing folding. This design uses three flips that are moved with DC motors on each flip. As the controlling unit to operate automatically use, the microcomputer (EV3 Brick) is connected with rotary encoder sensor; mechanical folding machine design is using LEGO mind storm EV3 robot module [2]. The use of this robot module aims to simplify the design because all the devices are easy to arrange. In order to the angular position of the flip to conform to the target, the used refractive control is proportional-integral-derivative (PID). PID is used to keep the deflection from the preserved flip angle according to its reference value [3–4]. The design of the PID controller is based on the model equation of the DC motor that contained in the LEGO mind storm EV3 robot module [3]. The given PID controller does not provide sufficient results on the performance of this folding machine prototype.

In each controller design, the modelling form of the plant is the most fundamental part to know the characteristic properties of the plant [5]. By knowing the characteristic properties of the plant, it can design the right controller and produce good performance [6]. In the folding machine, the plant that becomes the main purpose of control is the folding folder that is driven by the DC motor EMG30.

Modelling to obtain the plant model is using the relationship between the inputs, input components are difficult to obtain the value of some parameters. Under that matter, in this research will be applied a method of flip folder model identification model with EMG30 DC motor through output measurement offline data. Then do the testing and analysis on approach model to get the appropriate parameter.

2. Folding Machine

Folding machine is a tool that used in the process of folding clothes. This tool consists of 5 fold folders to be arranged in such a way that will form a fold of clothing. Each flip folder has a different area and angle of deflection. The arrangement of the flip can be seen in Figure 1, as well as in Figure 2. Shows the flip position when the deflection angle is 30^o. In each fold folder as the actuator component of the drive is a DC motor that is controlled by a microcontroller component. The rotary encoder sensor is used to measure the deflection angle that formed by the fold of the folder. The working mechanism of the folding folder will move each other alternately when the clothes are finished in the iron, and they are on the worktable; then the flip will start moving from start flip B. C, A, D and E.

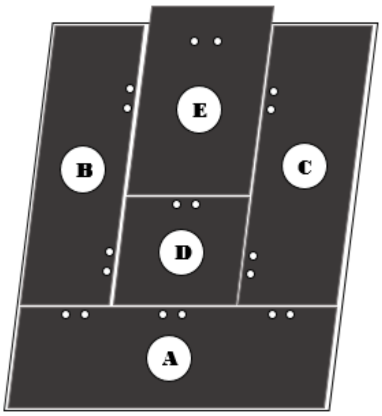

Figure 1. Compilation of flip folders folding machine.

Figure 2. Folding machine flip folder position.

3. Model Identification

3.1. Extended Least Square

The method of identification of plant parameters is done by going through the process of measuring input data and output in an offline condition. The input signal u (k) is given dynamically by giving a random signal to the system; the output y (k) of the system response will be recorded along with the input signal. Plant modelling is used the model form of the stochastic system with ARX model approach (Auto-Regressive Exogenous) [7]. The desired plant model has a 2nd order level, so the ARX plant model equation is as follows:

$$\frac{y(k)}{u(k)} = \frac{b_0 q^{-1} + b_1 q^{-2}}{1 + a_1 q^{-1} + a_2 q^{-2}} \tag{1}$$

In different equations, it can be represented as

$$\mathrm{y(k)} = -\mathrm{a_1 u(k-1)} - \mathrm{a_2 u(k-2)} + \mathrm{b_0 u(k-1)} + \mathrm{b_1 u(k-2)} \tag{2}$$

moreover, can be simplified to be

$$y(k) = \varphi^T (k-1)\theta \tag{3}$$

with

$$\varphi^{\mathrm{T}}(\mathrm{k}-1) = \begin{bmatrix} -\mathrm{y(k-1)} \\ -\mathrm{y(k-1)} \\ \mathrm{u(k-1)} \\ \mathrm{u(k-2)} \end{bmatrix} \theta = \begin{bmatrix} \mathrm{a_1} \\ \mathrm{a_2} \\ \mathrm{b_0} \\ \mathrm{b_1} \end{bmatrix} \tag{4}$$

where $\varphi^T(k-1)$ is the input and output measurement data and θ is the plant parameter.

The identification process is needed to obtain the parameter value of the plant (θ). By using the Extended Least Square method, this method is a recursive method through a quadratic gradient error formulation with a criteria function by involving all errors [7]. The parameter values of the plant will continue to be calculated until the error meets the minimum criteria as shown in equation (5) and (6).

$$J_{min} = \frac{1}{2} e^2 \tag{5}$$

$$\hat{\theta}(\mathrm{k}) = \theta(\mathrm{k}-1) + \mathrm{F(k)}\{\mathrm{y(k)} - \varphi^{\mathrm{T}}\theta(\mathrm{k}-1)\}\varphi(\mathrm{k}-1) \tag{6}$$

$$F(k+1) = F(k) - \frac{F(k)\varphi(k-1)\varphi^T(k-1)F(k)}{1+\varphi^T(k-1)\varphi(k-1)} \tag{7}$$

3.2. Root Mean Square Error

The model that will be obtained through the process of identification of plant parameters by using the method of Extended Least Square will be very diverse by the input signal given to the system. To find out the equation of model that close to the actual condition with the real plant, then this research is used RMSE (Root Mean Square Error). RMSE is the average root value of the square error which shows how big the error deviation value from the zero value. It can be written mathematically as equation (8).

$$\mathrm{RMSE} = \sqrt{\frac{\sum_{\mathrm{i}}^{\mathrm{n}} (\mathrm{y_i} - \hat{\mathrm{y}}_{\mathrm{i}})^2}{\mathrm{n}}} \tag{8}$$

where y_i is the identification data on the i-iteration, $\hat{y}_i$ is the approximate model data in the i-iteration and n is the sum of all data.

4. Result and Discussion

In model identification, the assignment is given a random input signal in the form of flip deflection angle position with the deviation of 0 to 150°. This condition is due to a mechanical design that limits the deflection limit of the flip. The identification process is done through three experimental variations to get mixed results, so it can be analysed to get the closest model. Furthermore, the identification of Extended Least Square is represented by the equation of transfer function model from each experiment. As a validation method, the RMSE is used to know how close the model with the real plant. The result of the identification process is obtained by the plant model that is shown in Table 1.

Table 1. Model identification result

Trial Number	Model	RMSE
1	$\frac{16.41\,s\,+\,4.167x10^{-4}}{s^2\,+\,1324\,s\,+\,4.191x10^{-4}}$	5,48
2	$\frac{18.28\,s\,+\,4.605x10^{-4}}{s^2\,+\,1286\,s\,+\,4.622x10^{-4}}$	5,28
3	$\frac{13.95\,s\,+\,3.475x10^{-4}}{s^2\,+\,1224\,s\,+\,3.481x10^{-4}}$	6,13

Table 1 shows the second experiment has the smallest RMSE value of 5.28. Therefore from the identification of flip folding machine plant model, the closest model is located in the second experiment. To know the response characteristics of the plant model that has been obtained, then it was tested by a step input signal for the system that composed by the open loop and closed loop and giving a reference of 1 rad angle. The result of the open loop and closed loop response is shown in Figure 3 and Figure 4.

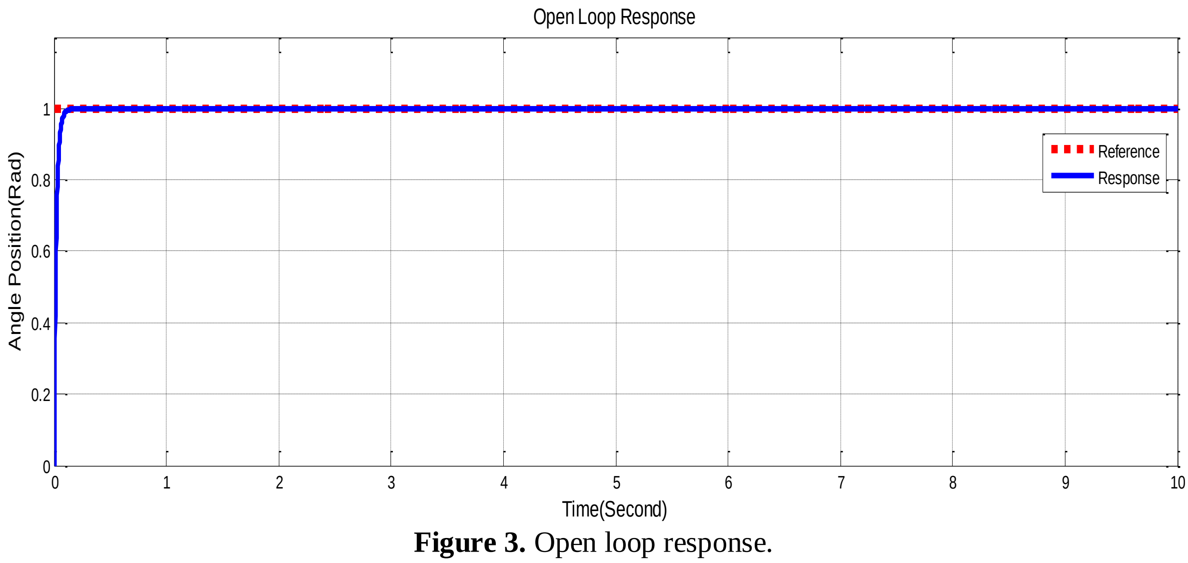

Figure 3. Open loop response.

Figure 3 shows the obtained open-loop response has the same characteristic properties with the 1st order system. It means the flip folder plant has a different real root value, so the system is second order and it is overdamped with the damping coefficient $\xi > 1$. This system can be approximated by the reduction model of the 1st order system. The characteristic of the transient response of this plant has a time constant (τ) = 0.1706 seconds, the rise time of 0.500 seconds, the settling time of 0.511 seconds and the delay time of 0.1178 seconds.

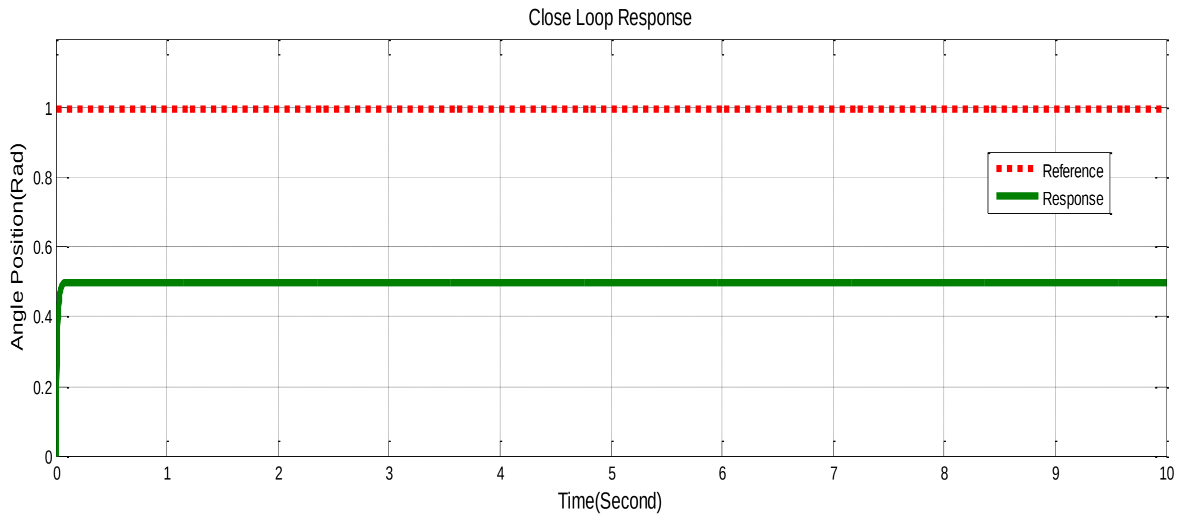

Figure 4. Closed loop response.

The analysis of the ability of the system in processing the error signal is prepared in a closed loop. Figure 4 shows the response system cannot reach the steady-state condition by the given reference with the steady-state error that occurs is equal to 50%. To overcome these conditions, the system is tested by providing a controller in order to reduce the value of the error. The Proportional Integral Derivative (PID) controller is the easiest method to be applied and most widely used on a conventional controller. To find out the results, then the PID controller is given to the system by using the trial and error method. The experiment is using the value of Kp = 1.5, Ki = 50 and Kd = 0.001. The PID results are shown in Figures 5 and 6.

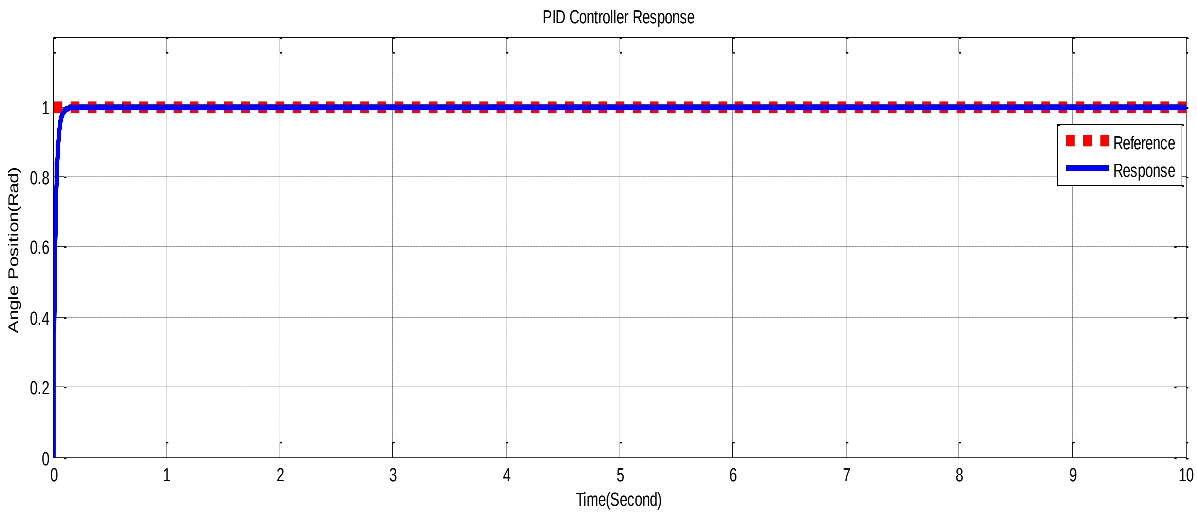

Figure 5. PID Controller Response.

The response results in Figures 5 and 6 shows the PID controller can keep the reference value as desired. Steady-state conditions can be obtained in 0.2763 with the transient response characteristics that having 0% steady state error, the time constant (τ) = 0.1742 seconds, rise time of 0.512 seconds, settling time of 0.522 seconds and delay time of 0.12 seconds.

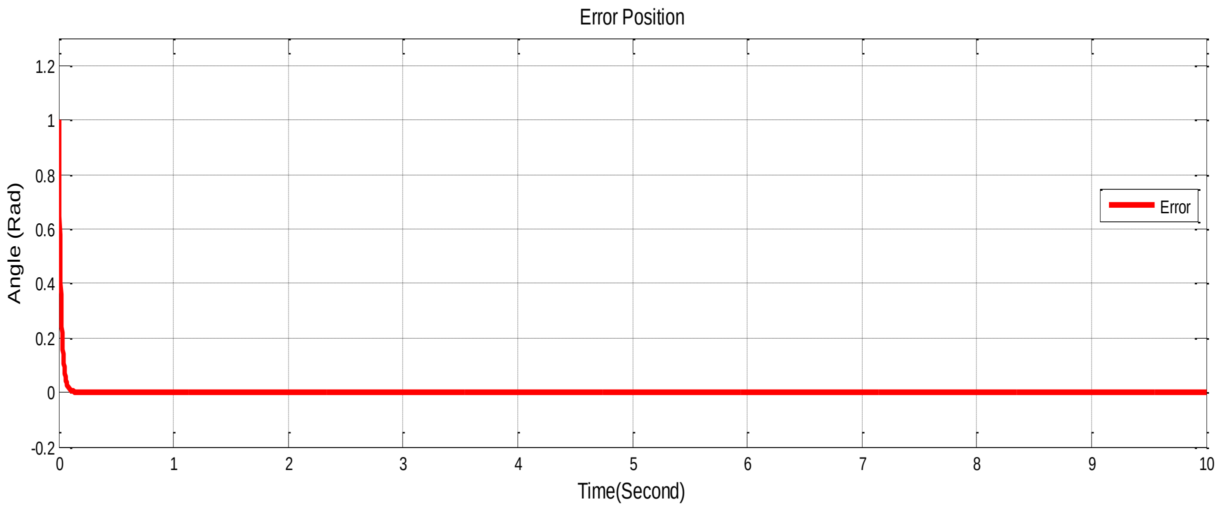

Figure 6. Error position response.

5. Conclusion

Based on the previous discussion it can be concluded that the process of identification of the plant by using Extended Least Square has produced the 2nd order equation. The properties of plant characteristics that have been obtained have some different real roots, so the plant is overdamped, and the 1st order reduction model can approximate it. The results of the PID controller show the controller performance which can reduce the position error steady state of 0%.

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