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MODEL IDENTIFICATION OF A LOW-COST ROBOT GRIPPER BY USING MATLAB SYSTEM IDENTIFICATION TOOLBOX (SIT)

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ABSTRACT

This paper describes the method of finding the estimated plant transfer function of a low-cost robot gripper system by using the MATLAB System Identification Toolbox (SIT).The best output signal of the gripper is obtained in particular by introducing a fast response step input (i.e. big slope) and a slow response step input (i.e. small slope).The test is based on the hardware setup which consists of a low-cost robot gripper, a closed-loop DC servo motor with position feedback, the Arduino IO hardware control and data acquisition. The results show that the obtained output signal is sufficient to represent the low-cost robot gripper transfer function by using a slow response step input. The PID control is employed and the results show that the gripping performance is satisfactorily achieved in simulation and experiment.

Keywords: system identification toolbox, DC servo motor, transfer function, arduino IO hardware control.

INTRODUCTION

Over the years, robot gripper has been invented for the application that require a fast and a reliable pickand place response. One of the criteria that usually produces a fast response is the choice of the DC motor. The key criteria for selecting a DC motor for the gripper is the accuracy of positional feedback control. The accuracy is determined by the analog to digital conversion resolution and system backlash or loads. High encoder resolution and minimum backlash gears are usually preferable.It is commonly found that built in encoder with current or voltage feedback is employed for the gripper (i.e. closing and opening gripper).

In automation industries where various types of robot grippers are used, modeling robot grippersby using a suitable system identification technique can be useful to optimize their performance. According to(Gevers, 2006)by performing system identification, high performance control can always be observed in simple models if some basic structure are accurately captured. A few general methods have been suggested when performing system identificationin particular for the DC motor (see Unbehauen & Rao 1998; Basilio and Moreira 2004; L. Ljiung 1999).

The obtained transfer function of the DC motor can be represented in the z-domain (discrete) or s-domain (continuous) depending on the complexity of the modeling.Some methods can be considered complex and time consuming such as employing the Physic laws(Abd Manan Samad, 2010).Nonetheless, most importantlyis to show that the obtained transfer function of any system is accurate and reliable. Usually the characteristic of the response matches atleast 90% of the actual plant(Faudzi *et al*., 2012).

A technique to quickly derive the mathematical modeling for the DC motor is by using System Identification Toolbox (SIT) from MATLAB.The SIT allows us to construct mathematical models of dynamic systems from measured input-output data. In addition, MATLAB SIT also provides a match percentage between input and output data of the plant (i.e. best fit) where users can easily determine the accuracy and reliability of the system data. Details information of the SIT can be found in (MathWorks, 1994).Several works based on the SIT have been reported in (Tajjudin *et al*., 2011) and (Adnan *et al*., 2012).A similar technique is considered in this study to derive the transfer functionmainly for the low cost robot gripper. The technique deploys a fast response step input (i.e. big slope) and a slow response step input (i.e. small slope). The most accurate model will be tested and analyse by using the PID controller.

HARDWARE SETUP

The hardware used in this study is the low-cost robot gripperthat attached with DC Servo motor. The gripper was inexpensive and easily found in the market. Moreover, the simplicity of the gripper design which includes a slot for the attachment of DC servo motorproduces a smooth and consistent gripping movement. The DC servo motor with the analog voltage feedback was introducedfor the purpose of finding the exact output data (i.e. angular position) of the plant. The analog feedback voltage of the DC servo motor was obtained through the build-in potentiometer located inside the servo motor. Itsvoltage isdirectly proportional to the motor angular position.In addition, the voltage range between 0 to 5 volts can be converted into angular values. Therefore, it has been identified that the angular range of the low robot gripper movement isbetween 21 Degrees (grip) to 92 Degrees (un-grip). The control signal and data acquisition wereexecuted by utilizing the Arduino IO package in which the Arduino acts as data acquisition hardware (DAQ) while transferring the control signal in serial connection.Moreover, the control signal of the servo motor was given through the digital pin while the analog voltage feedbackswasreceived through the analog input of Arduino Mega.The sampling rate for the input and output data is one millisecond where all data acquisition was executed in real time via MATLAB Simulink. The hardware setup is shown in Figure-1.

VOL. 11, NO. 14, JULY 2016 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

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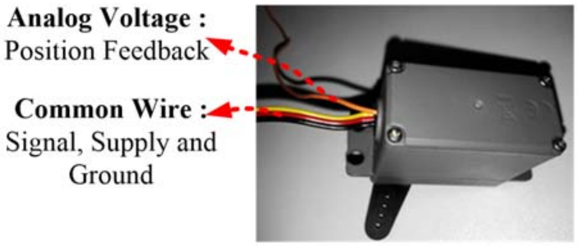

Figure-1(a). DC servo motor with analog voltage feedback.

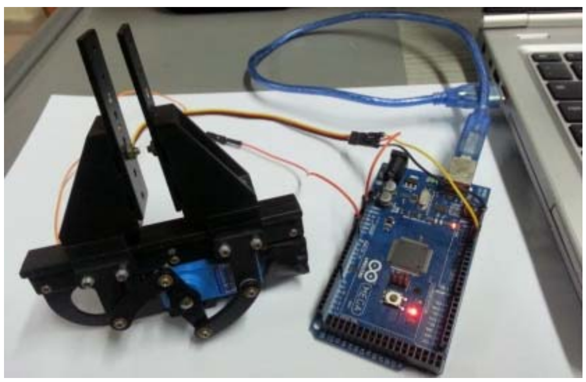

Figure-1(b). Complete hardware connection.

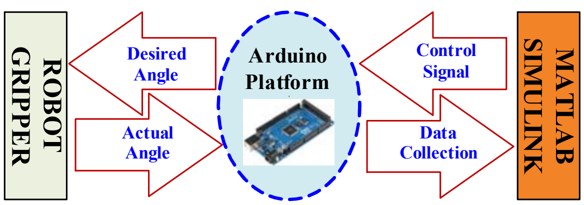

Figure-1(c). Hardware block diagram.

It is to note that a proper gripper setting can improve the quality of data acquisition. A preliminary hardware setting is crucial (i.e. chassis and Servo motor holder tightening) to optimize the gripper functionality before testing and analysing. Note that another key point that needs to be highlighted is the performance of the low cost robot gripper which is driven by the DC servo motor. The performance of two different motor conditions is observed where

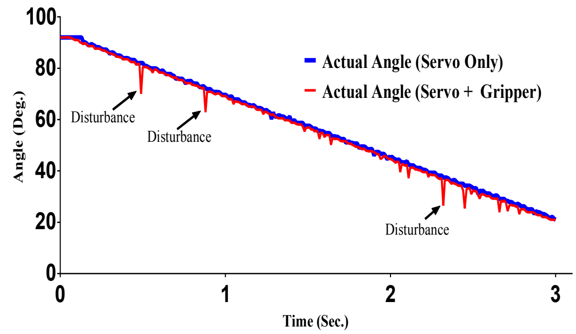

Figure-2. Performance comparison for "stand alone" servo motor against the servo motor attached to the robot gripper.

"stand alone" servo motor and the servo motor attached to the robot gripper are compared. The identical programming instruction was set for both conditions to gradually decrease the servo motor angular position from 92 Degrees to 21 Degrees in a sampling time of three seconds. A series of experiments carried out in this study comprises of optimal experiment design and data collection, model structure selection, model estimation and model validation (Hussain, Omar, and Samat, 2011). The acquired data were plotted in Figure-2 to compare the performance for both conditions.

The results show that the robot gripper performance is affected by the friction as compared to the "stand alone" servo motor in the presence of disturbances. The friction is mainly due to the movement of mechanism during the process of analog feedback from the servo motor. The same condition is also observed during the grip and un-grip operation of the gripper. This issue was also highlighted by(Zaki, Soliman, Mahgoub, and El-Shafei, 2010)where the nature of a mechanical system for a robot gripper contributes to the nonlinearities. Consequently, it may lead to the difficulty in controlling a slow robot gripper response. In this study, the nonlinearity factors are considered where the method of finding the robot gripper transfer function is based on the fast and slow response of the step input. These methods permit a clear understanding on how multiple approaches could affect the accuracy and performance of the transfer function by using MATLAB SIT.

MODEL EQUATIONS

Theoretically, the block diagram of a Servo motor system can be represented by a diagram as shown in Figure-3 (Ogata, 2012).

VOL. 11, NO. 14, JULY 2016 ISSN 1819-6608
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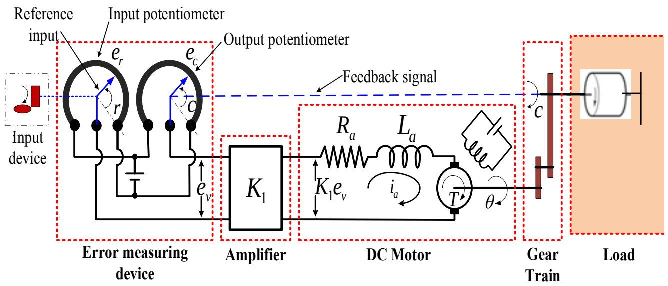

Figure-3. Servo motor system.

Based on Figure-3, the Servo angular position is proportional to the input and output potentiometer where the angular position r is the reference for the input potentiometer. Furthermore, in relation to input r, the output potentiometer determines the angular position c. The difference between r and c is the error signal e, or $e = r - c$. Therefore, an error voltage, e_v is produced from the potential difference of e_r and e_c.

$e_v = e_r - e_c$

where, $e_r = K_o r$ and $e_c = K_o c$

K_o : Proportionality constant

The error voltage is then amplified by the amplifier with the gain of K_1, to produce an input for the DC motor armature circuit, $e_a = K_1 e_v$. the error will then be reduced to zero by the motor rotation which is produced by a torque, T. By assuming a constant field current,

$T = K_2 i_a$

K_2 : Motor torque constant

i_a : Armature current

Moreover, an induced voltage e_b is produced during the rotation of the armature. Assuming a constant flux,

$$e_b = K_3 \frac{d\theta}{dt}$$

e_b : back emf

K_3 : back emf constant

θ : angular displacement of the motor shaft

In addition, the differential equation for the armature circuit is

$$L_a \frac{di_a}{dt} + R_a i_a + e_b = e_a$$

Or

$$L_a \frac{di_a}{dt} + R_a i_a + K_3 \frac{d\theta}{dt} = K_1 e_v \quad (1)$$

Correspondingly the torque equilibrium equation is,

$$J_o \frac{d^2\theta}{dt^2} + b_o \frac{d\theta}{dt} - T = K_2 i_a \quad (2)$$

J_o : Combined inertia of motor

b_o : Viscous-friction coefficient of the motor, load, and gear train referred to the motor shaft.

By eliminating i_a from the equations (1) and (2),

$$\frac{\Theta(s)}{E_v(s)} = \frac{K_1 K_2}{s(L_a s + R_a)(J_o s + b_o) + K_2 K_3 s} \quad (3)$$

Assuming the gear ratio of the gear train produces n rotation of the motor shaft, thus

$$C(s) = n\Theta(s) \quad (4)$$

The relation between $E_v(s)$, $R(s)$ and $C(s)$ is,

$$E_v(s) = K_o[R(s) - C(s)] = K_o E(s) \quad (5)$$

Thus, the transfer function for the feedforward path of servo system is,

$$G(s) = \frac{C(s)}{\Theta(s)} \frac{\Theta(s)}{E_v(s)} \frac{E_v(s)}{E(s)} = \frac{K_o K_1 K_2 n}{s[(L_a s + R_a)(J_o s + b_o) + K_2 K_3]}$$

For this type of Servo motor the inductance, L_a is small, thus it can be neglected, and the transfer function G(s) in the feed forward path becomes:

$$G(s) = \frac{K_o K_1 K_2 n / R_a}{J_o s^2 + \left(b_o + \frac{K_2 K_3}{R_a}\right) s} \quad (6)$$

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Additionally, the block diagram of the Servo system can be constructed by using equation (3), (4) and (5) as shown in Figure-4.

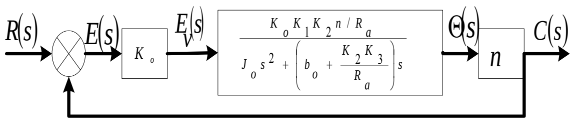

Figure-4. Block diagram of the servo system.

MODEL IDENTIFICATION

MATLAB has the capabilityto analyze and calculate a complex data, especially in linear and nonlinear environments.This study utilized System Identification Toolbox (SIT) from MATLAB where the modeling of the plant transfer function was obtained. The SIT requires a set of equally sampled data fromthe input and output of the robot gripper. In addition, the robot gripper hardware was set to be at an open-loop operation to obtain the precise output data from the plant. Once the data isgathered, the GUI for the SIT can be runthrough the MATLAB window. Two sets of input signal were tested, namely a fast response step input (i.e. big slope) and a slow response step input (i.e. small slope). It is to note that the fast response step input was used by (Elya *et al*., 2013) and (Tajjudin *et al*, 2011). Their results showed that the obtained transfer function of the DC motor can be *best fit*for 80%. Noted that the *best fit* was automatically computed by MATLAB. Hence, it is our aim to achieve best fit transfer more than 90% as recommended by (Faudzi *et al*., 2012). For that, different responses of step input were tested as summarized in Table-1.

Table-1. Method for the Plant Model Identification.

Test	**Input** (Desired)	**Output** (Actual)
Test 1	Step Response (Grip and Un-grip)	Measured by Arduino Mega
Test 2	Slope Δt=60 Second (Grip and Un-grip)	Measured by Arduino Mega
Test 3	Slope Δt=40 Second (Grip and Un-grip)	Measured by Arduino Mega
Test 4	Slope Δt=20 Second (Grip and Un-grip)	Measured by Arduino Mega

Referring to Table-1, the data for the desired angle (input) and the actual angle (output) of the robot gripper was measured by MATLAB Simulink Scope. Additionally, the data from the Scope was saved in the MATLAB Workspace,which can be imported into the SIT GUI. Figure-5 shows the MATLAB Simulink blocks that were used for all tests.

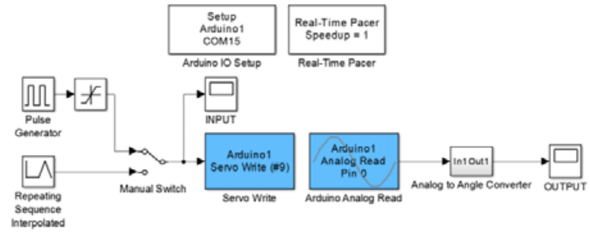

Figure-5. MATLAB simulink blocks (Open Loop).

The SIT GUI can be startedby typing "ident" at the MATLAB command window where theinput and output data from the Workspace can be imported. The GUI has the capability to analyse up to eight sets of data in a single session.Furthermore, the transfer function of the imported data can be estimated.The plant model identification by using the MATLAB SIT GUI is shown in Figure-6.

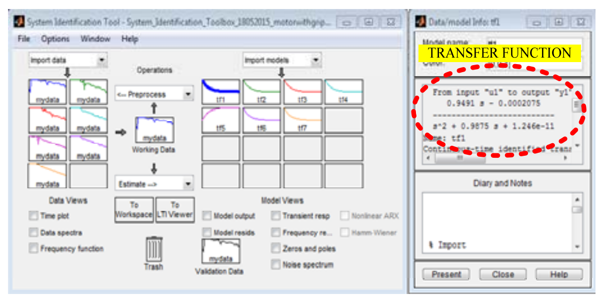

Figure-6. Plant model identification by using MATLAB SIT.

Referring to equation (6), the transfer function estimation for the second-order system was done in continuous-time (s-domain) with a single real zero and a pair of real poles. The data plot for input (desired) and output (actual) for all four tests are shown in Figure-7 together with the estimated transfer function, TF.

Test 1 :Step Response (Grip and Ungrip)

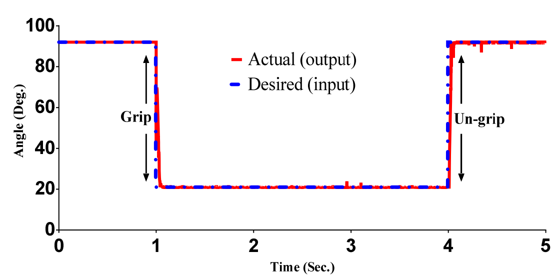

Figure-7 (a). *Test 1* input and output data plot.

$$TF_{test1}=\frac{0.006099s+0.00517}{s^2+0.1111s+0.005179}\ \textit{(96.42\%Best Fit)}$$

Test 2 :Slope Δt=60 seconds (Grip and Un-grip)

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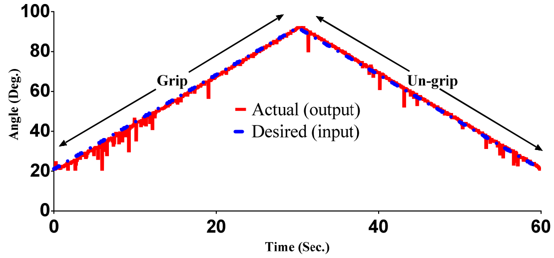

Figure-7 (b). *Test 2* input and output data plot.

$$TF_{test2} = \frac{20.7s + 0.002852}{2s^2 + 20.68s + 0.003084} \quad \textit{(95.33\% Best Fit)}$$

***Test 3* :**Slope Δt=40 seconds (Grip and Un-grip)

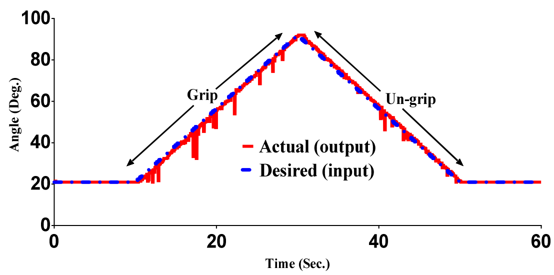

Figure-7 (c). *Test 3* Input and Output Data Plot.

$$TF_{test3} = \frac{21.2s + 0.177}{s^2 + 20.95s + 0.1761} \quad \textit{(95.9\% Best Fit)}$$

***Test 4* :** Slope Δt=20 seconds (Grip and Un-grip)

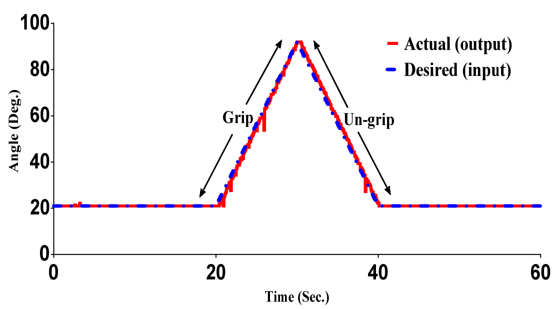

Figure-7(d). *Test 4* Input and Output Data Plot.

$$TF_{test4} = \frac{95.09s + 1.225}{s^2 + 96.15s + 1.25} \quad \textit{(95.88\% Best Fit)}$$

Based on the results in Figure-7, *Test 2* data plot indicates the highest disturbance during the grip or un-grip operation. This condition occurred due to the slow movement of the robot gripper which wasaffected by the frictionof the mechanical mechanism.Comparatively, it can be observed that the presence of disturbance decreasesas the response speed became faster as shown in *Test 3* and *Test 4*. Correspondingly, the estimated transfer function for each test was obtained with all the *best fit* percentage which was higher than 90%. This indicates that the data for input (desired) and output (actual) have high similarity in terms of response.The data plot proves that the higher speed of response (i.e. grip and un-grip), the higher the percentage of *best fit*for the estimated transfer function. However, to further analyze the results, two *validation* stages were introduced in this study. Firstly, the validation of an actual plant against the estimated transfer functions by a direct position response was conducted to identify which equations arethe most accurate representation of the low-cost robot gripper plant. Secondly, the comparison of a simple closed-loop control by using a PID controllerwas carried out to observe the response of the actual robot gripper against the selected transfer function representative of the plant modeling.

MODEL VALIDATION

As previously mentioned, the two validation stages are discussed.

Validation Stage 1: Direct response

The Simulink block diagram was set as shown in Figure-8 where the blocks of actual hardware and the estimated transfer function were made using the Arduino IO package.

Referring to Figure-9, it can be observed that the transfer function for *Test 1* (orange color)indicated the most inaccurate response of the plant modeling even though it previously produced the highest *best fit* percentage on SIT. To further analyze the results, a measurement of standard deviation for the data was carried out as shown in Table-2 to identify which of the estimated responses are most similar to the actual response of the plant. The standard deviation for the actual robot gripper response (blue color in Figure-9) is,

SD_{Actual} = 34.611

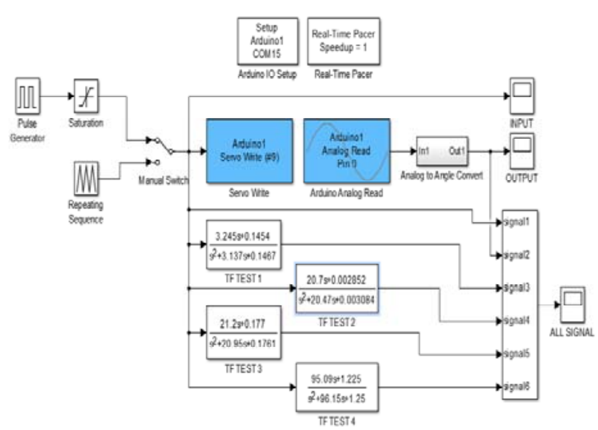

Figure-8. Simulink blocks for validation stage 1.

VOL. 11, NO. 14, JULY 2016 ISSN 1819-6608
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The data was captured for the grip and un-grip movement of the gripper and the results were plotted as shown in Figure-9.

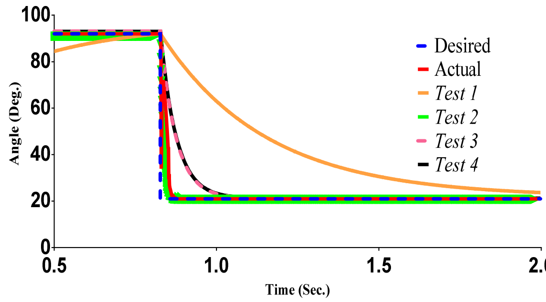

Figure-9 (a). Grip position response.

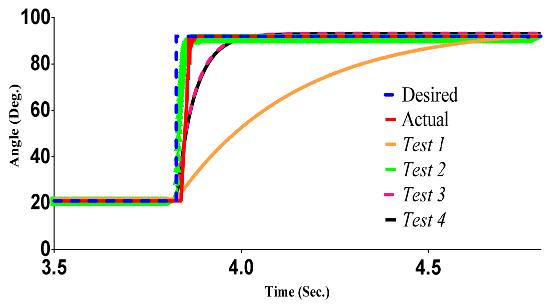

Figure-9 (b). Un-grip position response.

Table-2. Standard deviation of *Test 1* until *Test 4*.

Data	Standard Deviation (SD)	SD_{Actual} - SD_{Test}
Test 1	26.891	7.720
Test 2	34.167	0.444
Test 3	34.000	0.612
Test 4	33.934	0.678

Based on the results from Table-2, it is shown that the smallest [SD_{Actual} - SD_{Test}] value produced by*Test 2*(green color)indicated the highest similarity to the actual response data. Thus, the transfer function for *Test 2* was selected to be used for the second validation stage.

Validation Stage 2: PID closed loop control

The second stage of validation consists of a simple test for a closed-loop robot gripper system by implementing PID controller. The MATLAB Simulink block diagram is shown in Figure-10.

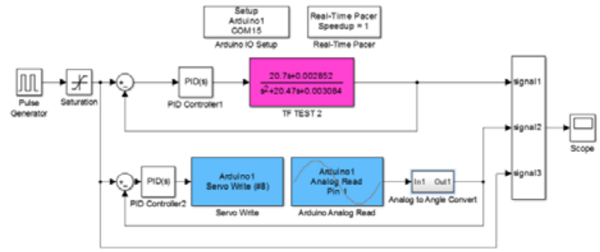

Figure-10. Simulink blocks for validation stage 2.

Based on Figure-10, the program was set to simultaneously monitor the closed-loop response of the actual plant and modeling plant with separated PID controllers. Initially, the data for the *un-tuned* PID controller was captured by using Simulink scope to monitor the initial response of both modeling and actual plants. Then, the PID controller was tuned to its optimized state to improve the system response. The results for*un-tuned* and *tuned* PID controller are shown in Figure-11.

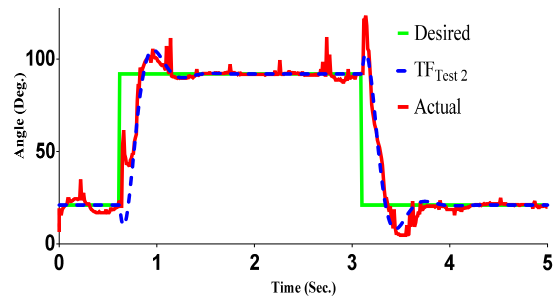

Figure-11 (a). Un-tuned PID controller.

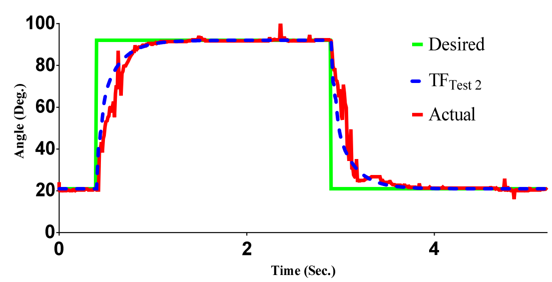

Figure-11(b). Tuned PID controller.

Based on the results in Figure-11(a), the presence of overshoot could be observed for the un-tuned system of both modeling and actual plants.The *un-tuned*actual systemfaced a significant disturbance with the response where the condition affected the grip and un-grip performance of the gripper.The method of tuning was done manually to obtain the most optimum response for the grip and un-grip movement. The results for the tuned system is shown in Figure-11(b) where the overshootwas eliminated. However, the performance of the actual system still contained a minor disturbance due to the nature of its mechanism. Table-3 shows the PID tuning parameter for the actual and modeling plant system.

Table-3. PID tuning parameter.

Parameter	Un-tuned		Tuned	
	$TF_{Test\ 2}$	Actual	$TF_{Test\ 2}$	Actual
P	-0.4	-0.3	1	-0.5
I	7	-5	9	-3.6
D	-0.045	-0.0005	-0.001	-0.000186

Table-4. Standard deviation comparison.

System	$SD_{Test\ 2}$	SD_{Actual}
Un-tuned	36.031	36.760
Tuned	33.339	34.628

Statistically, by referring to Table-4,it can be observed that the standard deviation for the *tuned*system (modeling and actual) has also improved. The standard deviation for the actual robot gripper performance has reached the optimized value (SD_{Actual} = 34.628) while the standard deviation for the plant model has slightly improved [$SD_{Test\ 2}$ = 33.339]. The results from the second stage of validation proved that the estimated transfer function can be used as the model representative of the low-cost robot gripper.The consistency of the standard deviation data showed that the estimated transfer function produced a consistent response for real system modeling(Fruk, Vujisić, and Špoljarić, 2013)

CONCLUSIONS

This paper provides a detailed description of the method to find the estimated plant transfer function of a low-cost robot gripper system by using the MATLAB System Identification Toolbox (SIT).The fast and slow responses of the step input were introduced to investigate the best estimated transfer function is. The results showed that the slow response step input produced the best estimated plant transfer function. The obtained transfer function is 95 % closed to the actual plant. The results also prove that the MATLAB SIT is able to estimate the transfer function for the low-cost robot gripper in the presence of friction and stiction. Likewise, better results can be expected for future studies which employ a higher quality robot gripper with high resolution encoder for positional feedback (i.e. 3 Finger Adaptive Robot Gripper by ROBOTIQ)

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