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DEVELOPMENT AND CONTROL DESIGN FOR LINEAR ACTUATED FINGER (LAF)

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Abstract

In this paper, Linear Actuated Finger (LAF) is developed by means of Solidwork® software. The model is fabricated using three-dimensional printer. The heart of the LAF is supported by a highly flexible, configurable and compact Miniature Linear Actuators (MLA). Motor driver is configured with the LAF system to ensure the drivability and controllability of the system. System identification approach is used to obtain the mathematical model of the LAF system where the system behaves as a type-0 third-order system. The identification phase exploits the input-output data that represented by the voltage-displacement relation of the LAF. To validate the controllability of the fabricated LAF system, Proportional-Integral-Derivative (PID) controller is designed by using Ziegler-Nichols tuning method. The transient and steady-state performance of the LAF is presented in the simulation results.

Keywords: Linear Actuated Finger(LAF); System identification; PID controller; Ziegler-Nichols Rules;

1.0 INTRODUCTION

The development of the myoelectric hand was invented by using a combination concept between electrical and mechanical forces in control system of an electrical prosthetic advanced introduced since 1965 [1]. The growing of compatible controller for prosthetic hand is provided to help amputee who had failing to using the physically wrist because incidentally lost all or part. The most prosthetic hand technologies do not have much different in terms of quality control related to human hand. The efficiency and efficacy of operational prosthetic hand can be increased by using a position feedback in order to improve the system performance in term of disturbance elimination or error handling [2].

The main issues incurred by prosthetic hand are robustness and less accuracy that often effect its smooth operation. Robustness can be defined as an ability of the system regain its performance when subjected by abnormalities [3]. One of robustness problem in prosthetic hand control system is dealing with nonlinear term such as backlash in the gearing system, motor saturation and dead zone. The appearance of exogenous disturbance also catastrophic to model inaccuracies that result in non-asymptotic positioning of the finger operating under actuated mechanism.

Generally, the prosthetic hand incurs some functional limitations in terms of grasping, slippage control, vibrations, and enabling corrective control techniques. In this work, the DC voltage that behaves as an input signal is applied to the LAF. The angular displacement is the output of the LAF where asymptotic poisoning of the angular displacement is to be controlled [4]. The input signal will provide as reference and used to recognize the performance of dc linear motor functional. The voltage signal will put as a reference into the plant and provided the positioning angle as output to be control. The test and result output is cover for a positioning of fingers hand via simulation and will recorded to provide the improving suitable robust controller of the LAF. The LAF is designed and fabricated so that it mimics human finger movement where its peripherals consist of linear actuator, electrical instrument, processing control system and few instruments. As such, this research restricted to one degree of freedom (DOF) design.

The Proportional-Integral-Derivative (PID) is a control loop feedback mechanism (controller) commonly used in industrial control systems [5]. It has been reported that more than 95% of the controllers in the industrial process control applications are of PID types as no other controllers match its simplicity [6]. PID provides clear functionality, applicability and ease of use and tuned [7]. Because of its high reliabilities, flexibilities and low costs, PID is utilized to control DC motors based industrial applications such as robot manipulators and home appliances where speed control is vital [8]. PID controllers provide robust and reliable performance for most systems if the PID parameters are tuned properly. Various tuning methods are available in industry [9] [10]. Among the tuning methods, the Ziegler-Nichols (ZN) technique has been very influential [11].

This paper has two main contributions. Firstly, the design of the LAF that governs the actuator selection to ensure high precision of positioning finger, speed, accuracy, motion, slippage control and grip ability. The use of linear dc motor is due to highest torque, lower speed and a built-in feedback encoder to perform the position control of the finger. Secondly, PID controller is designed for third-order LAF system by means of Ziegler-Nichols method. The controller parameters are fine-tuned by the table and calculation to ensure satisfactory performance.

This paper has been organized as follows, Section-II explains plant descriptions. Section-III describes an experimental setup and system identification. Section-IV describes results and analysis of PID controller with Ziegler-Nichols tuning. Section-V concludes the findings.

2.0 PLANT DESCRIPTIONS

Linear Actuated Finger (LAF) is known as the prosthetic finger that consists of one Degree of Freedom (DOF) that required to attract only one of jointer linkages in linear movement for each finger. The LAF has three linear motors that behave as actuator. The linear motor needs encoders to provide feedback transmitter. The feedback transmitter transmits position knowledge from the finger in term of electrical signals that suitably controlled by the control apparatus. Transient and steady-state performance of the hardware in the loop system in closed–loop operation is favorable in the design objectives.

The LAF plant is designed by using Solidwork® software. The fabrication of the prototype LAF is produced by using three-dimensional (3D) printer. The material of the LAF structure is composed by using Acrylonitrile Butadiene Styrene (ABS) due to advantages over polystyrene. The ABS is durable, shiny, rubbery substances and toughness even at low temperature.

Miniature Linear Actuators (MLA)

The unique of Miniature Linear Actuators (MLA) enables a new generation of motion-enabled product design, with capabilities that have never before been combined in a device of the size. This MLA is a small linear actuators are a superior alternative to designing with awkward gears, motors, servos, and linkages. The LAF is a micro Firgelli's L series of micro linear actuators combined with the best features of existing micro actuator families into a highly flexible, configurable a compact platform with an optional sophisticated on-board microcontroller. The first member of the L series, the L12, is an axial design with a powerful drivetrain and a rectangular cross section for increased rigidity. But by far the most attractive feature of this actuator is the broad spectrum of available configurations. Table 1 shows the MLA specifications.

Table 1. MLA Specifications

Weight	34 g
Max Speed (no load)	12 mm/s
Mechanical Backlash	0.1 mm
Feedback Potentiometer	2.75 kΩ/mm ± 30%, 1% linearity
Duty Cycle	20 %
Life Time	1000 hours at rated duty cycle
Peak Power Point	23 N @ 6 mm/s
Backdrive Force	80 N
Audible Noise	55 dB at 45 cm
Stall Current	450 mA at 5 V & 6 V, 200 mA at 12 V

Basis Operation of MLA

The MLA actuator is designed to move push or pull loads along its full stroke length. The speed of travel is determined by the gearing of the actuator and the load or force the actuator is working against at a given point in time as shown in Figure 1. When power is removed, the actuator stops moving and holds its position, unless the applied load exceeds the back-drive force, in which case the actuator will back-drive. Stalling the actuator under power for short periods of time (several seconds) will not damage the actuator. Only the precaution to the supply polarity need to be considered where the supply voltage polarity cannot be reversed during integrated controller option.

Each MLA actuator equiped with two mounting clamps, two mounting brackets and two rod end options, named a clevis-end and a threaded-end-with-nut. When changing rod ends, the actuator can be extended completely while the round shaft is hold when unscrewing the rod end. Standard lead wires are 28 AWG, 30 cm long with 2.56 mm (0.1") pitch female header connector (HiTec™ and Futaba™ compatible). Actuators are a sealed unit with roughly IP–54 rating, resistant to dust and water ingress but not fully waterproof.

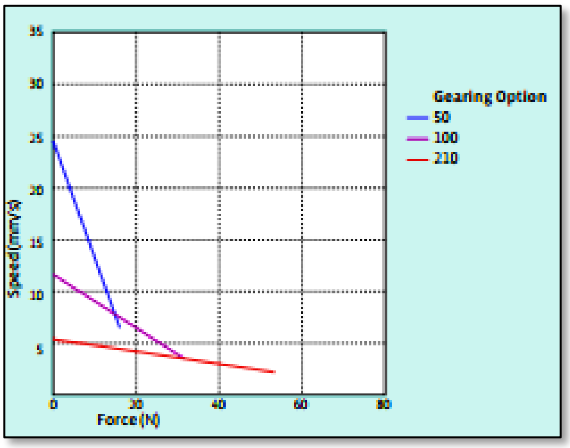
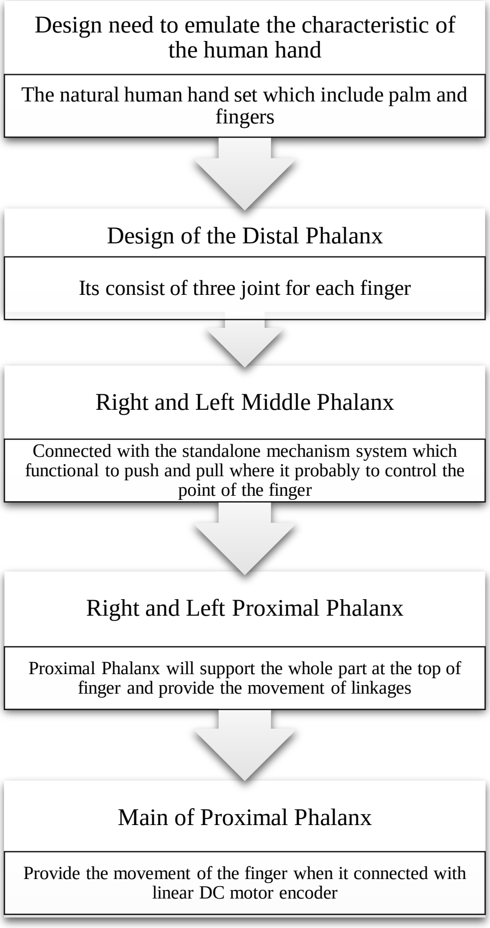


Fig. 1. Load Curve Graph

Designing LAF

The design and fabrication phases of the LAF is depicted in Figure 2. The completed LAF is shown in Fig. 3.



Design need to emulate the characteristic of the human hand

The natural human hand set which include palm and fingers

Design of the Distal Phalanx

Its consist of three joint for each finger

Right and Left Middle Phalanx

Connected with the standalone mechanism system which functional to push and pull where it probably to control the point of the finger

Right and Left Proximal Phalanx

Proximal Phalanx will support the whole part at the top of finger and provide the movement of linkages

Main of Proximal Phalanx

Provide the movement of the finger when it connected with linear DC motor encoder

Fig. 2. Flowchart

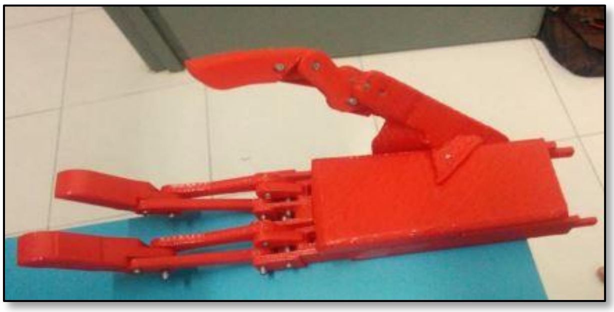


Fig. 3. Linear actuated finger (LAF)

3.0 SYSTEM DESCRIPTION

Experimental Setup

Figure 4 shows the experimental setup to facilitate system identification process. The myRIO is connected with computer to provide analog feedback facility for the input and output motor driver. As myRIO is compatible only to National Instrument LabView software, the graphical user interface in Labview is constructed in order to gather the input-output vector. The expected result from system identification process is the valid transfer function of the LAF. This process demanding several test and experimental work-out.

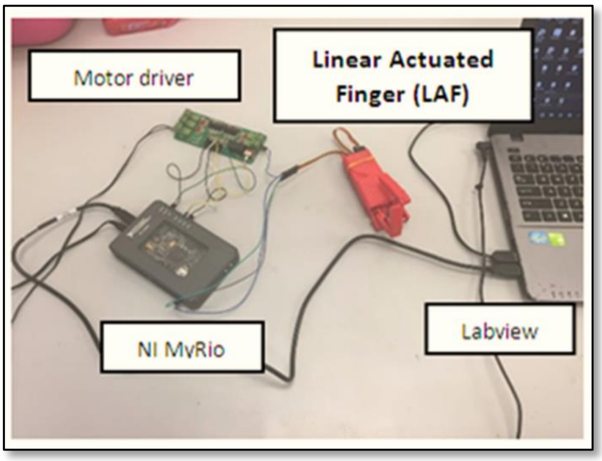


Fig. 4. Experiment setup and configuration

Eq. 1 shows the relationship between the parameter need to be considered by applying the equation of gradient. The calibration between voltage and displacement can be analyzed by the equation.

$$y = mc + \theta \qquad (1)$$

where;
c = voltage (V)
y = displacement (mm)

System Identification

By means of MATLAB Identification Toolbox, the mathematical model of the LAF is obtained. In the system identification process, important criteria such as residual analysis for model correlation, pole-zero location, frequency response and best fits can be recorded in order to estimate the LAF model. Figure 5 indicates the best fits from the system identification process in MATLAB Identification Toolbox.

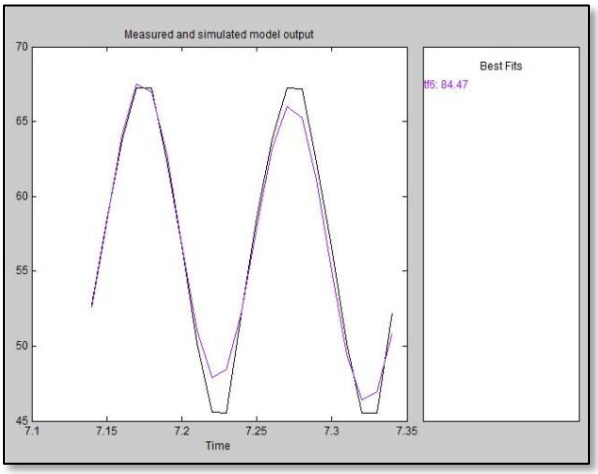


Fig. 5. Measured and simulated model output yields best fits 84.47

Figure 5 shows the measured and simulated model output of the LAF. Validation data shows 84.47% best fit, meaning that the estimated model is nearly track the real output data from the experiments. This model is considered a valid model because the best fit is obtained above 80%. The balance 15.53% are losses because of nonlinear factor such as a dead zone, friction and backlash.

Pole-Zero Location

Examining the pole and zero locations is useful for stability and identifying near-canceling pole-zero for model simplification. Figure 6 depicts the pole-zero location of the mathematical model obtained from system identification process. The LAF system is stable as the plot shows that all poles are located in the left half plane of the s-plane.

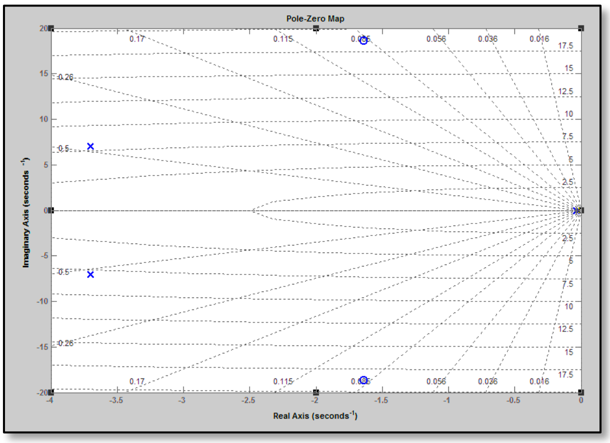


Fig. 6. Zero-Poles Locations

4.0 RESULTS AND ANALYSIS

PID Controller

To observe the performance of the LAF system, Proportional-Integrate-Derivative controller (PID) controller is formulated to gain the position tracking of the angular displacement. The system configuration is shown in Figure.7.

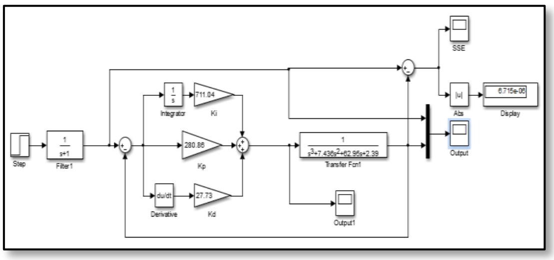


Fig. 7. PID controller block diagram in Simulink MATLAB

PID is has several advantages in minimizing the error between a set point and the system response. The control algorithm contains three terms gain namely proportional, integrate and derivative terms. A continuous PID controller is described by the following transfer function Eq. 2 and Eq. 3.

$$GC(s) = P + I + D = KP + Ki/s + KdS \quad (2)$$

$$GC(s) = KP\,(1 + 1/TiS + TdS) \ldots. \quad (3)$$

Kp is the proportional gain, Ki is the integration coefficient and Kd is the derivative coefficient. Ti is known as integral action time and Td is referred as derivative action time. Such a controller has three different adjustments (Kp, Ti & Td), which interact with each other. For this reason, it is very difficult and time consuming to tune these parameters in order to get the best performance according to the design specification required by the system. The design of the PID controller is done by using ZN-rules, and it is based on the mathematical model obtained from the identification phase with a higher order system with transfer function shows in Eq. 4.

$$G(s) = \frac{0.9471s^2 + 3.11s + 332}{s^3 + 7.436s^2 + 62.95s + 2.39} \quad (4)$$

Ziegler-Nichols Rules

The method is a trial and error tuning method based on sustained oscillations that was first proposed by Ziegler and Nichols. The method is the most known and the most widely used method for tuning of PID controllers. It is also known as online or continuous cycling or ultimate gain tuning method. Table 2 below shows ZN-rules;

Table 2. Ziegler-Nichols rules

Controller	Kp	Ki	Kd
P	0.5 ku	-	-
PI	0.45 ku	0.54 ku /Tu	-
PID	0.6 ku	1.2 ku /Tu	0.6 ku Tu /8

The result is obtained from calculation based on Ziegler-Nichols tuning method and therefore the parameters of PID gains are small. Table 3 shows the controller responses for step input position tracking for close-loop system. The overshoot percentage, %OS is 0%, peak time, Tp is 276.5210s, settling time, Ts is 102.6014s, rise time, TR is 77.2033s and percent steady state error (%ess) is 0.000006715%. And it shows that the closed-loop system exhibits small overshoot and low settling time Ts with small steady state error ess. Figure 8 shows the positon response of the plant.

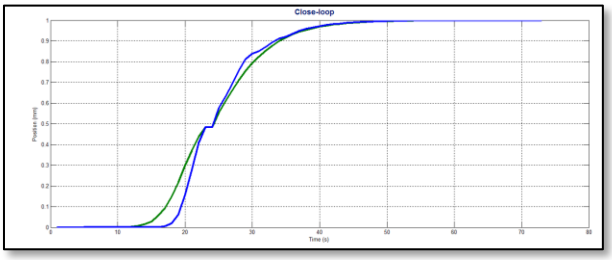


Fig. 8. Position response

Table 3. Specifications controller responses for position tracking.

Specifications	Controller PID
Proportional Gain (Kp)	280.86
Integral Gain (Ki)	711.04
Derivative Gain (Kd)	27.73
Percent Overshoot (%OS)	0
Peak Time (TP)	276.5210
Settling Time (TS)	102.6014
Rise Time (TR)	77.2033
Percent Steady State error (%ess)	0.000006715

The result shown is applied to the system without disturbance and additional load. In future works, real time control with load and exogenous disturbance will be considered.

5.0 CONCLUSION

The paper deals with development and fabrication of LAF. Solidwork® software is utilized in the design phase. Furthermore, the fabrication process of the prototype LAF is developed using 3-D printer. The LAF dynamic of mathematical modeling is obtained via system identification toolbox in MATLAB where the transfer function of the system is produced. The PID controller is formulated by Ziegler-Nichols technique in order to ensure the controllability and transient as well as steady-state performance of the LAF. The approach is validated using MATLAB with SIMULINK toolbox.

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