Modelling of Flexible Manipulator System Using Flower Pollination Algorithm

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***Abstract*— The study of the flexible manipulator system (FMS) has attracted many researchers due to its superiority of light weight and faster system response. Flexible manipulator system is an improvement from its rigid structure, however it can be easily vibrated when it subjected to disturbance. If the advantages of FMS are not to be sacrificed, an accurate model and efficient control system must be developed. Thus, this study presents an approach of evolutionary swarm algorithm via flower pollination algorithm (FPA) to model the dynamic system of flexible manipulator structure. An experimental rig of flexible manipulator system was developed for input-output acquisition. Then, this input-output data was fed to system identification method to obtain a dynamic model of flexible manipulator system utilizing evolutionary algorithm with linear auto regressive with exogenous (ARX) model structure. The result obtained through flower pollination algorithm was then compared with conventional method known as least square (LS) algorithm in terms of mean square error (MSE), correlation test and pole-zero diagram. The best MSE achieved by LS modeling for endpoint acceleration and hub angle positioning are 0.0075 and 0.0028, respectively. While, the best MSE produced by flower pollination algorithm for endpoint acceleration and hub angle positioning are 0.0063 and 0.0020, respectively. It is reveals that the performance of intelligence algorithm is superior than conventional algorithm.**

Keywords—Flower pollination algorithm, evolutionary swarm algorithm, flexible manipulator, system identification

I. INTRODUCTION

Nowadays, flexible manipulators have been employed in many industries especially in automation and manufacturing fields, spacecraft and aircraft engineering which required that the weight of mechanical structures to be kept as low as possible. Flexible manipulators are designed to increase the productivity through its faster system response and higher manipulation speed while simultaneously consume lower energy due to its lighter weight [1]. Therefore, flexible manipulator systems have received substantial attention in recent years and being utilized in more complex tasks such as assembling and working at unmanned places [2].

However, the flexibility of the flexible manipulators can be easily affected by vibration when subjected to disturbance forces due to its low stiffness. The vibration will occur during maneuver and become more severe especially at higher speed motion [3]. This unwanted vibration will reduce the accuracy during positioning of flexible manipulator and thus its effectiveness. Thus, it is crucial to model and control this non-linear dynamic of the system.

This study represents part of the continuous effort in finding accurate dynamic model with intelligent optimization technique associating real input output data from experimental study in improving flexible manipulator system. Many researches had used system identification technique to developed variety of models. The system identification will establish a mathematical model and estimate model parameters that can represent the behaviour of the system based on input-output of the system [4]. Several researchers still applied this method since it is well developed and widely used to solve parametric modelling problems [5,6].

Swarm algorithm are among of the evolutionary algorithm group that have been successfully used to compute the parameter values in any difficult applications. One from this class is flower pollination algorithm (FPA). FPA is a newly developed heuristic optimization method based on pollination of flowers. Yang investigate FPA on benchmark functions. Results showed that the performance of FPA outperforms Genetic Algorithm (GA) and Particle Swarm Optimization (PSO) algorithm [7]. Emary and his friends presents FPA for the optimization of retinal vessel segmentation. Results indicated that FPA has very fast convergence and robust even with abnormal images [8]. FPA has better quality solution and robustness because it has capabilities such as extensive domain search with quality, consistency solution and its performance encourage to implement for present problem [9].

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This paper presents the modeling of flexible manipulator system using system identification technique optimize via flower pollination algorithm in comparison to least square algorithms. System identification is carried out using input - output data that was acquired experimentally based on previous research [10]. The obtained model will be validated based on input/output mapping, mean square error (MSE), correlation test and pole zero stability diagram.

II. EXPERIMENTAL SETUP

Single link flexible manipulator system that constrained to move in horizontal position was developed. The mechatronic system consists of mechanical, instrumentation and computer aspects. A thin aluminium alloy of flexible manipulator link is pinned and attached to the motor at one end while free at the other end. The properties of the aluminium link is provided in Table I. Figure 1 shows the schematic diagram of experimental setup that was conducted in order to acquire the input-output data of flexible manipulator system for system identification purpose.

TABLE I. PROPERTIES OF THE ALUMINIUM LINK

Parameter	Specification
Length (mm)	600
Width (mm)	40
Thickness (mm)	1.5
Young's Modulus (GPa)	71
Mass density per area (kg/m^2)	2710

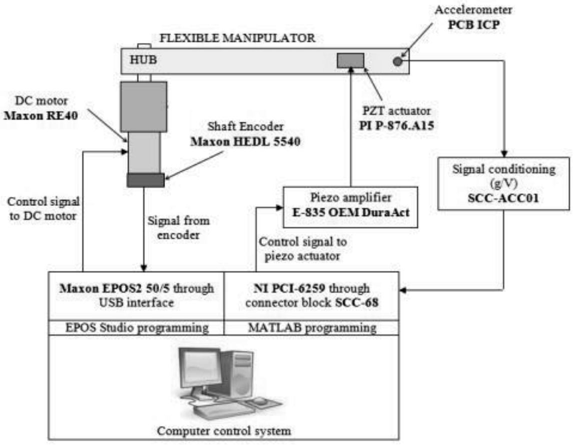


Fig. 1. Schematic diagram of flexible manipulator system

The comprehensive instrumentation components include in this study are sensors, actuators and a computer with a programmable software. In this study, piezoelectric and DC motor acts as actuators while accelerometer and encoder is used as sensors. The flexible link was driven by the DC motor which attached directly at the hub of rotational axis. Therefore, the speed and angle displaced could be controlled easily via PC connection. Encoder that are attached directly to the motor will control the position of the flexible manipulator link by adjusting the angle with precision of 500 counts per turn. Meanwhile, an accelerometer is employed to measure the vibration and placed at endpoint of the flexible link because it's the location where maximum vibration will occur. Piezoelectric actuator is mounted on the surface of flexible link for vibration control purpose that will be utilize for future analysis. It is responsible to produce control signal that can attenuate the endpoint vibration.

Signals from accelerometer and to the piezo actuator was interfaced by data acquisition system (DAQ) and can be connected to the PC for data analysis. The experimental setup for system integration to measure the hub angle and endpoint acceleration of flexible manipulator are shown as in Figure 2.

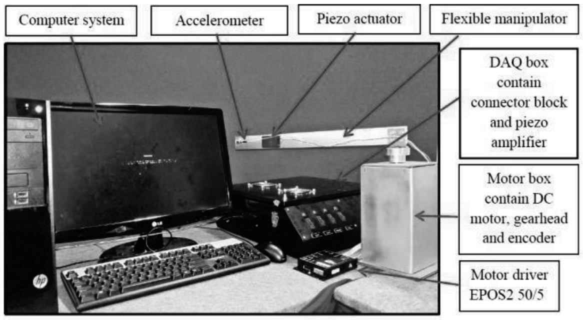


Fig. 2. Experimental setup for system integration

The result obtained was verified with impact test that was conducted and compared thoroughly. The frequency response of the experimental result with added sensors and actuators was compared with the impact test result that has been tested on the bare link structure. It is noted that reasonable accuracy was obtained from comparison for the first three modes of vibration. For the primary first vibration mode obtained from experimental result is 3.01 Hz while impact test result is at 3.05 Hz. Comparison shows very close results with percentage of error below 5 percent which validates the suitability of the collected experimental input-output data to be used [10].

III. SYSTEM IDENTIFICATION

System identification is the building of mathematical models of dynamic systems from observed input-output data [4]. The function of system identification is to replace the real system with the mathematical expression. This expression creates a similar relationship between input (u) and output (y) signal. Prior to that, an appropriate order and parameters for the model is essential to be determine that best fits that relation. In this study, the identification of flexible manipulator was optimized via ARX model structure given by:

$$y(t)=\frac{B\left(z^{-1}\right)}{A\left(z^{-1}\right)}u(t)+\frac{\xi(t)}{A\left(z^{-1}\right)} \tag{1}$$

where $A\left(z^{-1}\right)$ and $B\left(z^{-1}\right)$ expressed as

$$A\left(z^{-1}\right)=1+a_1z^{-1}+\ldots+a_nz^{-n}$$

$$B\left(z^{-1}\right)=b_o+b_1z^{-1}+\ldots+b_nz^{-(n-1)}$$

z^{-1} is a backshift operator, white noise, $\xi(t)$ is equal to zero, n indicates the orders of the model while $[a_1,\ldots,a_n,b_1,\ldots,b_n]$ are model parameters that need to be optimized. $y(t)$ and $u(t)$ is the system output and input vector, respectively. Thus, an identified model of the system can be represented in terms of transfer function form $H(z^{-1})$ as follows

$$H\left(z^{-1}\right)=\frac{B\left(z^{-1}\right)}{A\left(z^{-1}\right)}=\frac{b_o+b_1z^{-1}+\ldots+b_nz^{-(n-1)}}{1+a_1z^{-1}+\ldots+a_nz^{-n}} \tag{2}$$

In this study, the minimization of mean-squared error (MSE) function is set as an objective function for optimization formula. Two optimization tools are employed in determining the parameter of ARX model which are least squares (LS) and flower pollination (FPA) algorithms. For both optimization, total samples observed were 15000 and 7500 of the samples were chosen for training and the rest was used for testing. Heuristic technique was used to obtain the best model of the system.

IV. RESULTS AND DISCUSSION

The performance of FPA in models the flexible manipulator system was compared with the conventional LS algorithm. Identification of the flexible manipulator was fed with the experimental input-output data obtained. Two sets of input-output data were acquired experimentally which represents hub angle positioning and endpoint acceleration. The performance is observed in terms of input/output mapping, MSE, correlation test and pole-zero stability diagram.

FPA was tuned heuristically by varying the number of population, probability switch, upper and lower boundary, number of iterations and orders for each set of hub angle and endpoint acceleration respectively. Results with smallest MSE were recorded. Table II shown the FPA parameters used to achieve best result.

TABLE II. SET OF PARAMETERS IN FPA

Parameters	**Endpoint Acceleration**	**Hub angle**
Population size	20	20
Probability switch	0.8	0.6
Number of iteration	2000	400
Upper and lower boundary	2,-2	4,-4

The best model for endpoint acceleration modelling was obtained by FPA with an order of 4 while hub angle modelling achieved the best result with an order of 2. The best results of FPA algorithm achieved and the model parameters represent in transfer function form are shown in Table III.

The modelling output of endpoint acceleration in time and frequency domains obtained are shown in Figures 3 and 4, respectively. Figure 5 shows the poles and zeroes mapping and its corresponding correlation test is illustrated as in Figure 6. While, Figure 7 represents the FPA modelling output of hub angle in time domain. The poles and zeroes mapping with its corresponding correlation test are shown as in Figures 8 and 9 for hub angle modelling, respectively.

From Table II, it is noticed that the requirement for parameters setup in hub angle modeling was less as compared to endpoint acceleration modelling especially the number of iterations. This is due to the simpler set of hub angle modeling which involve one-step input data only as in Figure 7. This explained the hub angle convergence reached optima faster than endpoint acceleration modeling that requires large variety of data and more complex. This situation also clarified the different orders used for both modeling that best fit the optimization to reach minimum MSE.

From Figures 3 and 7, it is noted that the simulated output using FPA was very close to each other which indicates the model has successfully characterized the system dynamics for both endpoint acceleration and hub angle, respectively. The first mode of vibration was captured at 3.052 Hz as shown in Figure 4, which is very near to the vibration modes obtained through impact test result with percentage of error less than one percent. Figures 5 and 8 shows all the poles lied inside the circle unit which indicates the stable model for both modelling respectively. The corresponding correlation tests as in Figures 6 and 9 for endpoint acceleration and hub angle, respectively, confirming an adequate model fit where results were within 95% confidence interval.

The flexible manipulator system was then modelled using LS algorithm for both hub angle and endpoint acceleration behaviour with an order of 2. The best result of LS algorithm obtained are depicted in Table III. The model parameters were presented in term of transfer functions also shown in Table III.

The modelling output of endpoint acceleration in time and frequency domains obtained are shown in Figures 10 and 11, respectively. Figure 12 shows the poles and zeroes mapping and its corresponding correlation test is illustrated as in Figure 13. While, Figure 14 represents the LS modelling output of hub angle in time domain. The poles and zeroes mapping with its corresponding correlation test for hub angle modelling are shown in Figures 15 and 16, respectively.

From Figures 10 and 14, it shows that both LS modelling output for endpoint acceleration and hub angle was matched the actual output from experimental setup. From Figure 11, the first vibration mode from LS endpoint acceleration output is at 7.28 Hz which is quite far from the vibration modes obtained through impact test on experimental rig. For poles and zeroes mapping as in Figures 12 and 15 for endpoint acceleration and hub angle respectively, all poles lied inside the circle unit indicating the stable model. However, the correlation test were found to be outside of 95% confidence interval range which not satisfied the correlation test requirement as illustrated in Figures 13 and 16.

From Table III, the corresponding results reveals that the identification using FPA has outperformed LS for both endpoint acceleration and hub angle. This is shown as in Figures 17 and 18 where FPA modeling was closely matched the actual output from experimental setup for both endpoint acceleration and hub angle respectively. The FPA model provides the best representation of the physical system with minimum MSE value, high stability in the pole-zero stability diagram and good correlation test. Besides that, the LS modelling were shown to be biased and not correlate at 95% confidence interval for both endpoint acceleration and hub angle.

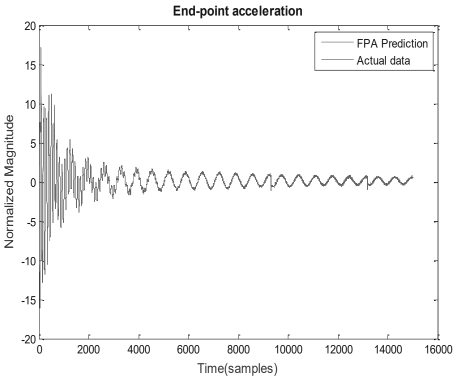


Fig. 3. Actual and FPA modeling in time domain for endpoint acceleration

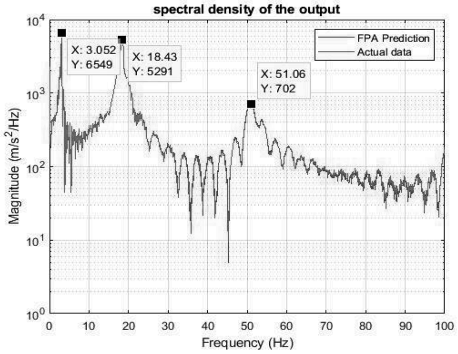


Fig. 4. Actual and FPA modeling in frequency domain for endpoint acceleration

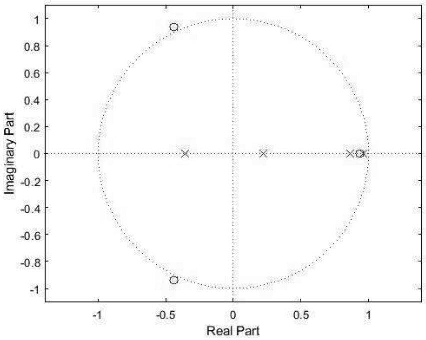
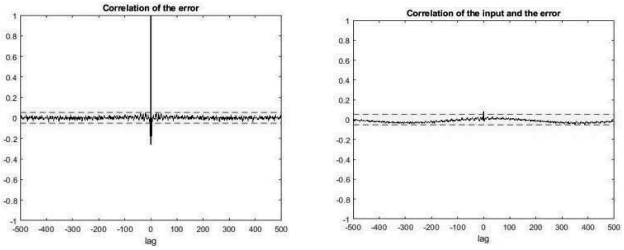


Fig 5. Pole zero diagram of FPA modeling for endpoint acceleration



(a)

(b)

Fig 6. Correlation tests of FPA modeling for endpoint acceleration: (a) Auto correlation, (b) Cross correlation

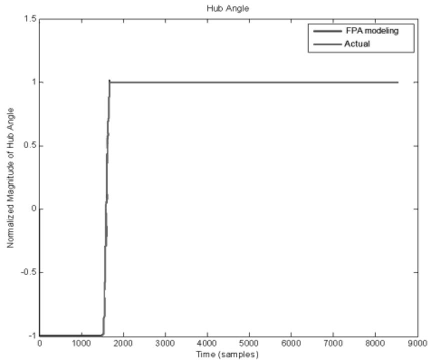


Fig. 7. Actual and FPA modeling in time domain for hub angle

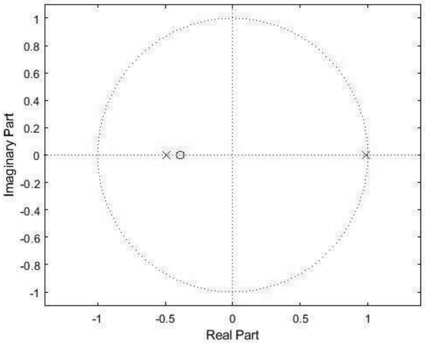
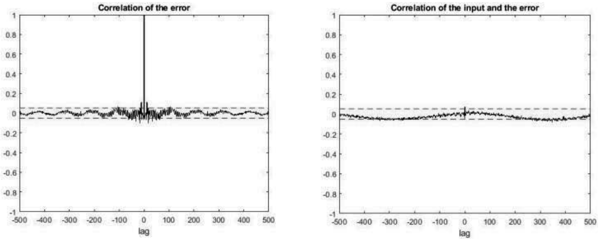


Fig 8. Pole zero diagram of FPA modeling for hub angle



(a)

(b)

Fig 9. Correlation tests of FPA modeling for hub angle: (a) Auto correlation, (b) Cross correlation

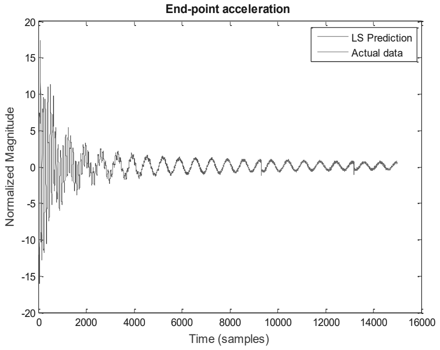


Fig. 10. Actual and LS modeling in time domain for endpoint acceleration

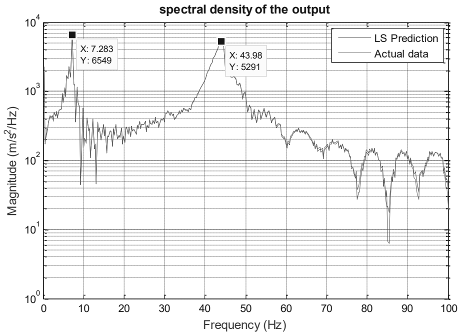


Fig. 11. Actual and LS modeling in frequency domain for endpoint acceleration

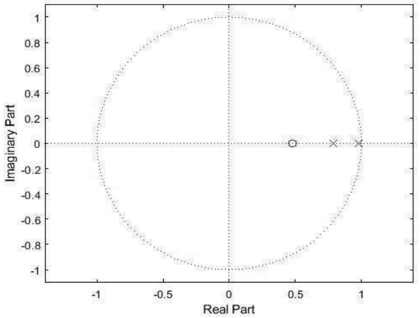
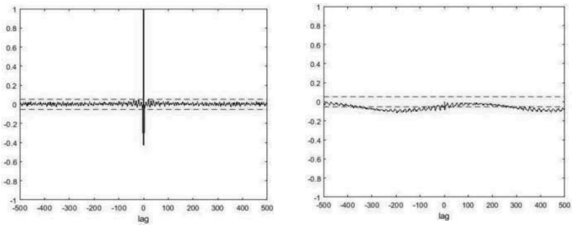


Fig 12. Pole zero diagram of LS modeling for endpoint acceleration



(a) (b)

Fig 13. Correlation tests of LS modelling for endpoint acceleration: (a) Auto correlation, (b) Cross correlation

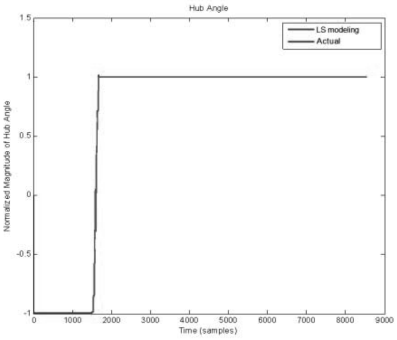


Fig. 14. Actual and LS modelling in time domain for hub angle

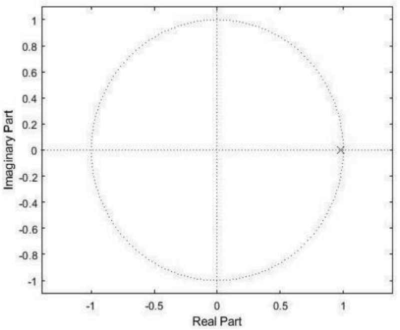
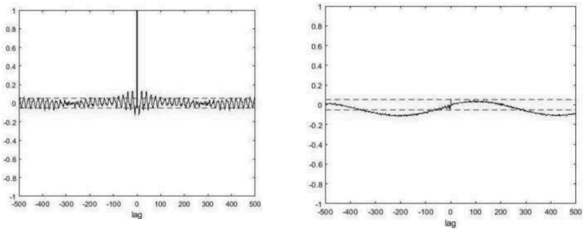


Fig 15. Pole zero diagram of LS modelling for hub angle



(a) (b)

Fig 16. Correlation tests of LS modelling for hub angle: (a) Auto correlation, (b) Cross correlation

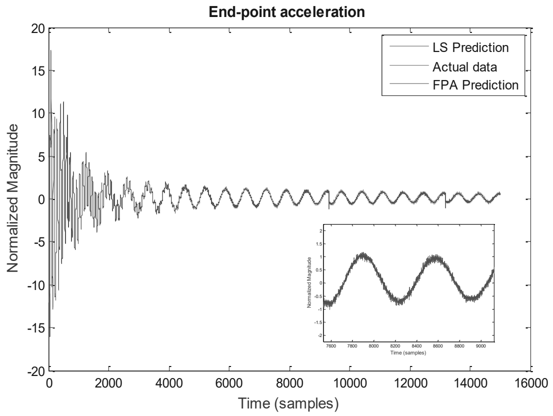


Fig 17. Performance comparison for endpoint acceleration modeling by each approach.

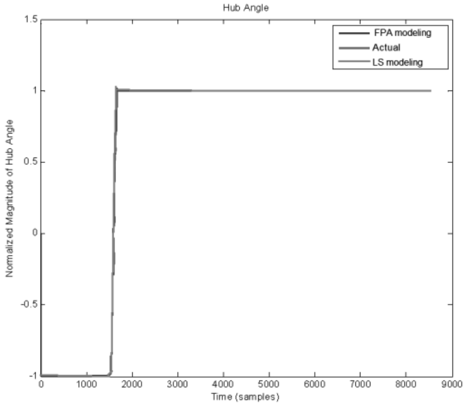


Fig 18. Performance comparison for hub angle modeling by each approach.

TABLE III. COMPARATIVE ASSESSMENT

	Modeling domain	MSE	Transfer function
Endpoint acceleration	FPA	0.0063	$H_1(z)=\frac{0.2706z^{-1}-0.01413z^{-2}+0.06885z^{-3}+0.2738z^{-4}}{1-1.694z^{-1}+0.5119z^{-2}+02527z^{-3}-0.06505z^{-4}}$
	LS	0.0075	$H_3(z)=\frac{0.2864z^{-1}-0.1372z^{-2}}{1-1.765z^{-1}+0.7692z^{-2}}$
Hub angle	FPA	0.0020	$H_2(z)=\frac{-0.014z^{-1}+0.01862z^{-2}}{1-0.515z^{-1}-0.4792z^{-2}}$
	LS	0.0028	$H_4(z)=\frac{-0.006526z^{-1}+0.03057z^{-2}}{1-0.5165z^{-1}-0.473z^{-2}}$

V. CONCLUSION

In this study, FPA techniques is utilized to modelled the flexible manipulator system in comparison with conventional LS technique. Validation tests were carried out through input/output mapping, MSE, pole-zero diagram and correlation tests. Prior to that, an experimental setup of single-link flexible manipulator constrained to move in horizontal direction was developed. Input output data was collected through experimental setup. Then, the acquired experimental input output data for endpoint acceleration and hub angle was fed to the system identification. It is noted that the FPA modelling technique has performed better in approximating the system response than LS modelling. The approach adopted form the basis for the subsequent investigations of vibration control of flexible manipulator system.

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