Practical Modeling and System Identification of Electric Servo Motor

Ahmed Samir Mohamed, Samy Samir Mohamed
Military Technical College, Egypt

Supervisor: Ahmed Nasr Ouda, Mohamed Alaa
Military Technical College, Egypt, Mohamed.alaa@mtc.edu.eg

Abstract– An R/C servo motor is a compact package of DC geared-motor associated with position servo controller. They are widely used in small-sized robotics and mechatronics by virtue of their compactness, easiness-to-use and high power/weight ratio. However, in order to improve control performance of mechatronic systems using R/C servo motors, such as biped robots or under-actuated systems, it is crucial to clarify their mathematical model. This paper describes the development and modeling of motor using system identification methodology. The development of controllers is considered the most crucial issue. An experimental test was carried out to record and analyze the motor input/output signals in open loop system. The experiments showed that it was feasible to represent the dynamic characteristics of the motor using the system identification technique.

Keywords—ARMAX. OE, BJ.

I. INTRODUCTION

Building motors has drawn dramatic attention which is one of the motivating topics in both robotics and automotive engineering research. R/C servo motor is a popular name for a sort of compact DC geared-motor packages including motor drivers and position servo controllers, where R/C stands for Radio- Control as shown in Fig. 1 [1]. R/C servo motors were originally developed for hobby use such as radio-controlled vehicle or aircraft. In the last decade, they have been widely used in the field of robotic systems by virtue of their compactness, high torque-weight ratio, cost performance and easiness-to-use; conversely, high demands raised by recent robotics has been boosting the development of R/C servo motors. Nowadays, R/C servo motor is a reasonable choice to realize compact and less expensive mechatronic systems.

Fig. 1 Overview of an DC servo motor.

Control of a motor to obtain an accurate mathematical model to be controlled is considered the main challenge. For this purpose, system identification techniques are introduced in order to solve such problem.

System identification methodology was introduced to study the performance of a developed dynamic system and estimate its mathematical model by observing input/output signals. These signals consist of a mathematical expression that precisely defines the input and output relationship. System identification has a long history in solving significant problems in the field of autonomous systems and robotics. For example; kinematic modeling and the calibration of robotic manipulators; parameter identification and nonlinear modeling, adaptive control and neural network-based system identification, estimation of inertial parameters, and the prediction of the environment.

Eng. [1] introduced online identification for an autonomous underwater vehicle dynamics model using an experimental test. In addition, Garg [2] discussed several modeling methods and types of models using system identification such as black-box, gray-box, white-box, and parametric, non-parametric system identification. Lai [3] developed a system identification model to identify the pitch, roll, and yaw dynamic models for a small unmanned helicopter, then a software-in-the-loop was developed for the estimated model.

Mendes [4] introduced an identification model of a wheeled mobile robot with a differential drive. The robot has been modeled by Multiple Input and Single Output (MISO) Hammerstein systems with input dead zones. The robot dynamic model is based on the traveled distance increment instead of the robot coordinates, making the model linear and allowing the application of classical methods of identification. Both parameters of linear and nonlinear blocks are estimated simultaneously through application of recursive least squares. Hasiewics [5] developed a system identification model for block-oriented dynamic nonlinear systems. The Hammerstein and Wiener system has been investigated. In addition, the advantages of parametric and non-parametric identification techniques were discussed.

The first controller was used to control the speed and the other one was for steering control. Antonelli [8] introduced a path following algorithm based on a fuzzy logic controller.

The proposed controller emulates human driving behavior. The controller uses the information of the curvature of the desired path ahead and the distance between the vehicle and the next bend in order to drive the vehicle safely. On the other hand, the controller output is the maximum value of the linear velocity. Sahoo [9] designed a controller for tracking the desired heading angle for an unmanned ground vehicle considering the limits on rotation of steering wheel and steering motor rate. A two-degree-of-freedom vehicle model is considered for the controller design.

In this paper, the main contribution is the development and modelling of a motor using system identification technique. This research concerned with system identification of ’from position-reference to position’ relationship which has been scarcely dealt with, as opposed to some conventional works on ’from velocity-reference to velocity’ relationship for DC servo drivers.

This paper is organized as follows. In Section II, we introduce a historical background of mathematical modeling based on SI. The continuous-time system identification approach is explained in Section III. The simulation results and analysis in highlighted in section IV. Finally, the Conclusion of the paper is given in Section V.

III. SYSTEM IDENTIFICATION

Generally, SI is the process of modelling system dynamics based on the measured input/output signals via an experimental test. It has the capability to provide an accurate mathematical model of the system dynamics. The SI approach has five steps [7] as shown in Fig. 2 experimental design, (2) data retrieval, (3) parameter estimation algorithm and system identification model selection, (4) model validation, (5) model implementation. If the model validation is not good enough to represent the actual model of the system dynamics, the first three steps will be repeated again until the model validation achieves assigned level of accuracy.

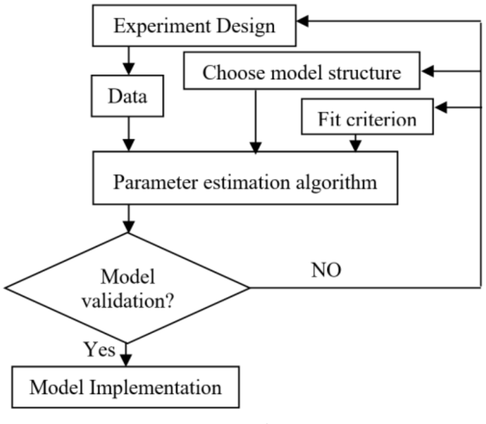

Fig. 2 System Identification procedure.

System identification using parametric identification techniques has a specific model structure. The parameters are estimated using the observation of the input/output data. In addition to providing a large variety and possibilities regarding different ways of describing the system, where the output of system Y(Z) can be defined as follows.

$$Y(z) = G(Z)X(Z) + M(Z) \tag{1}$$

Equation (1) can be rewritten to be as following

$$Y(z) = G(Z)X(Z) + H(Z)\mathrm{E(Z)}$$

$$Y(z) = \frac{N(Z)}{D(Z)}X(Z) + \frac{A(Z)}{B(Z)}\mathrm{E(Z)} \tag{2}$$

Where Y(z) is the n_y output, X(z) is n_x the input, E(z) is the transform of a white noise, ∈(t), G(z) is the transfer function of the system, H(z) is the stochastic behavior of noise, The modeling of motor model will be considered by applying ARX, ARMAX, BJ, OE, SS, and TF models. The characteristics of each model were studied in [11].

The ARX model in Equation (3) is considered the simplest estimation model as shown in Fig. 3. The main weakness is the disturbance model (1/N(z)) that comes with the system’s poles. Consequently, an incorrect estimation of the system dynamics can be accrued due to the term A in Equation (2). Accordingly, this issue can be avoided by the requirement of higher orders coefficients of terms A, B, where the signal to noise ratio is acceptable.

$$D(Z)Y(z) = N(Z)X(Z) + E(Z) \tag{3}$$

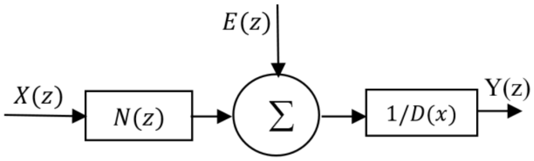

Fig. 3 ARX model.

The ARMAX model in Equation (4) has the capability to handle the disturbance modeling compared with ARX model. For this purpose, ARMAX is considered the most popular model that can be used in many applications. The block diagram of the ARMAX model is shown in Fig. 4.

$$D(Z)Y(z) = N(Z)X(Z) + A(Z)E(Z) \tag{4}$$

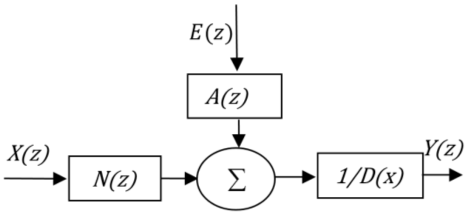

Fig. 4 ARMAX model.

The OE models Equation (5) and the block diagram the OE model is shown in Fig. 5. This model has the capability to describe the dynamics of the system separately. Meanwhile, there are no wasted parameters on the disturbance model. The main advantage of this model, it has the capability to estimate the correct transfer function $G(z) = N(z)/D(z)$. If there isn't feedback during collecting the data.

$$Y(z) = \frac{N(Z)}{D(Z)} X(Z) + E(Z) \tag{5}$$

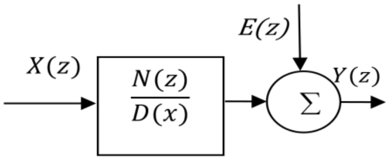

Fig. 5 OE model.

The disturbance properties of the BJ model are modeled separately from the system dynamics (6). The block diagram of the BJ model is shown in Fig. 6.

$$Y(z) = \frac{N(Z)}{D(Z)} X(Z) + \frac{A(Z)}{B(Z)} E(Z) \tag{6}$$

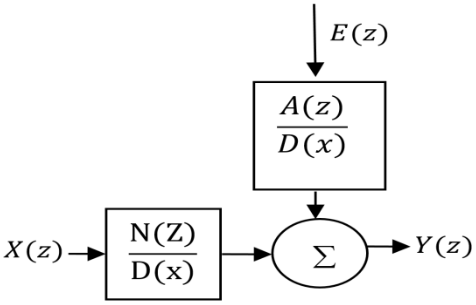

Fig. 6 BJ model.

Using the SS model, the state-space form is the best way to describe a linear system as described in Equation (7).

$$\begin{aligned} \dot{X} &= Ax(t) + Bu(t) \\ y(t) &= Cx(t) + Du(t) + \upsilon(t) \end{aligned} \tag{7}$$

where the relationship between the input $u(t)$ and the output $y(t)$ is defined via the nx-dimensional state vector $x(t)$.

A. SYSTEM IDENTIFICATION ALGORITHM

System Identification starts by selecting a model structure followed by the computation of an appropriate model in the structure. The selected model will be evaluated afterward. Figure 7 shows this process which can be summarized as follows:

Step 1: Record the input/output signals to/from the vehicle.

Step 2: Examine the data and select useful portions of the original data.

Step 3: Estimate input delay to gain a better insight into the dynamics via obtaining the impulse response of the system.

Step 4: Select and define the appropriate identification model structure within which the model of the system can be obtained.

Step 5: Choose the best model structure corresponding to the input/output data and the given fit to estimation criterion.

Step6: Examine the obtained model's properties (pole-zero configurations).

Step7: If the selected model is good enough to represent the identified system, then stop; otherwise go back to the fourth step to try another model set. Possibly also try another estimation method in the fifth step or work further on the input-output data obtained in first and second steps.

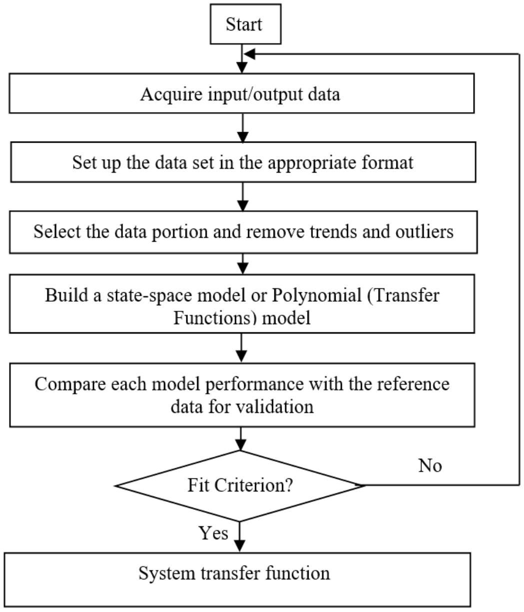

Fig. 7 System Identification procedure flowchart.

B. Experimental Setup

In this section, the experimental setup for recording and analyzing the input/output signals will be discussed. A rotary encoder Compensated is used to provide the motor speed as shown in Fig. 8.

Fig. 8 Rotary encoder

The rotary encoder will be interfaced with Arduino to save the obtained input/output signals data on an SD card during the test as shown in Fig. 9.

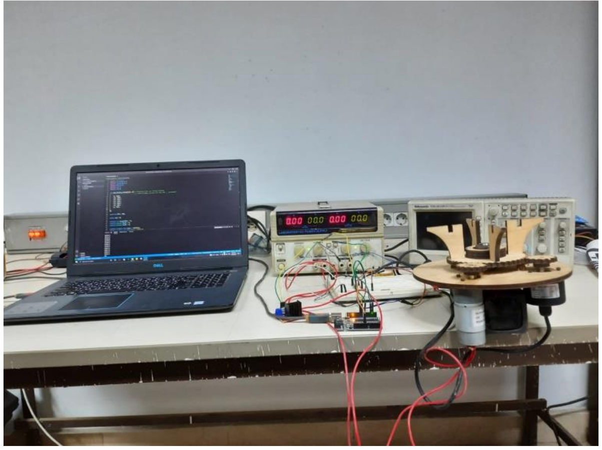

Fig. 9 Experimental test setup

The speed of the motor is predetermined within the Arduino code, where the desired rotor rate is subtracted from the actual rate measured by the number of pulses acquired by the encoder. The difference error is mapped to PWM signal applied to the power amplifier to enlarge the applied current to the motor. Gradually, the difference error is eliminated and the consequent rate is applied to be executed. The obtained motor model includes the motor driver, the feedback encoder, and the embedded microcontroller, as the system identification process identify the proposed system between the applied input and the acquired output.

IV. SIMULATION AND RESULTS

In this section, the input/output data is recorded and analyzed to deduce a model as shown in Figure 10

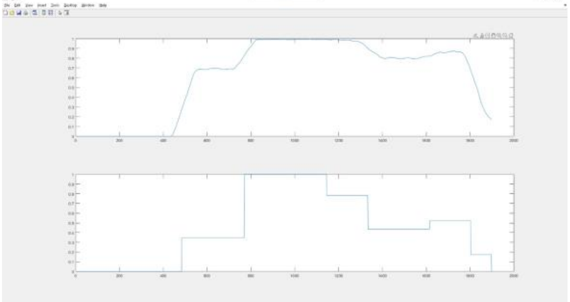

Fig. 10 Experimental results for the recorded input and output signals

The system identification toolbox using MATLAB software will be used to develop the motor dynamic model. First the data is loaded on MATLAB command window, the recorded inputs and output data are set, then the command “ident “opens the system identification toolbox interface. The step response of the motor will be displayed as shown in Figure 11 which represent the nonlinear inputs/output relation.

IV. CONCLUSION

In this paper, we proposed a simple and realistic model of the R/C servo motor where the input is the reference speed and the output is the measure speed. Based on the result of continuous-time system identification experiment under various relative-degree assumptions, we deduced that the internal model of the embedded servo is a nonlinear model. All sorts of R/C servo motors can be identified, basically, using the approach we showed in this paper. Finally, let us re-emphasize the benefit we could obtain from this study. We have a mathematical model of the R/C servo motor; now the control/robotics researchers can deal with compact mechatronic systems using R/C servo motors (such as hobby humanoids), with the full aid of advanced control/robotic theories. The authors are currently engaged in modeling and system identification of under-actuated mechatronic systems including the R/C servo motors.

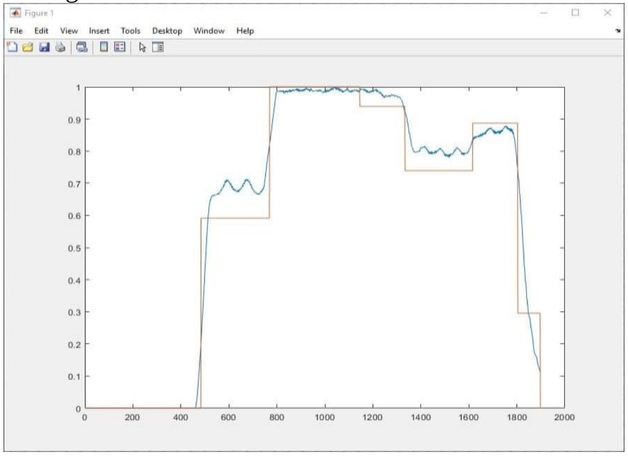

Fig. 9 Input/output tracking response

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