# SYSTEM IDENTIFICATION OF A SERVOMOTOR USING ARX MODEL FOR VIRTUAL SPEED SENSING

*João Gabriel da A. Calmon [a], João Vítor S. Mendes [a], Emanuel Benício de A. Cajueiro [b]*

*[a] Robotics dept., SENAI CIMATEC, Brazil.*
*[b] Automation dept., SENAI CIMATEC, Brazil.*

**Abstract:** This paper presents the application of dynamic system identification methodology to obtain a mathematical model for estimating the rotor speed of a servomotor based on a PWM signal. Velocity control is frequently combined with position control to enhance dynamic system response and enable optimal control. The model acts as a virtual sensor and uses an autoregressive model with exogenous inputs (ARX) due to system's weakly nonlinear traits. During validation, the estimated ARX model successfully inferred servomotor speed with 97.85% accuracy compared to real system's measured signal. The methodology demonstrated effectiveness in speed estimation for various systems with low complexity and cost velocity control, supporting the possibility of replacing conventional sensors with mathematical models.

**Keywords:** dynamic system identification; velocity control; servomotor.

# IDENTIFICAÇÃO DE SISTEMA DE UM SERVOMOTOR UTILIZANDO MODELO ARX PARA SENSORIAMENTO VIRTUAL DE VELOCIDADE

**Resumo:** Este artigo apresenta a aplicação da metodologia de identificação de sistemas dinâmicos para obter um modelo matemático capaz de estimar a velocidade de rotação de um servomotor com base em um sinal PWM. O controle de velocidade é normalmente combinado com o controle da posição para melhorar a resposta dinâmica do sistema e permitir controle ótimo. O modelo atua como um sensor virtual e utiliza uma estrutura autorregressiva com entradas exógenas (ARX) devido às características fracamente não-lineares do sistema. Durante a validação, o modelo ARX estimado inferiu com sucesso a velocidade do servomotor com uma exatidão de 97,85% em comparação com o sinal medido do sistema real. A metodologia utilizada demonstrou eficácia na estimativa de velocidade para vários sistemas com controle de velocidade de baixa complexidade e custo, apoiando a possibilidade de substituir sensores convencionais por modelos matemáticos.

**Palavras-chave:** identificação de sistemas dinâmicos; controle de velocidade; servomotor.

## 1. INTRODUCTION

In motion control systems, such as servomotors, continuous velocity control is often sought after, not just position control. Controlling the velocity in a servomotor allows the designer not only to maintain the velocity close to the reference value but also to employ this variable to optimize position control [1].

Among the reasons why it is desirable to consider velocity feedback, and not only position feedback, when aiming to control the position of servomotors, one can mention: attenuation of abrupt accelerations and decelerations at the initial and final positions since velocity feedback improves the dynamic response of the system, enabling it to respond more quickly to variations in the position reference [2]. Another benefit is the ability to achieve displacement with a velocity close to the reference value, even in scenarios with variable loads, making the system more resistant to this type of disturbance. Furthermore, it enables the use of advanced control techniques, such as optimal, predictive, and adaptive control [3].

Moreno, Kelly, and Campa [4] point out speed control as an important problem, both theoretically and practically, in applications with robotic manipulators. This is because velocity information is used as an input to the kinematic controller for positioning and orientation of the end-effector, which is only possible when appropriate velocity controllers are employed.

Mokhlis, Sadki, and Benassi [5] performed system identification for a servomotor, using the established set-point as input and angular position as output. The authors analyzed the step response of the ARX and ARMAX models and obtained better results with the latter. However, in their analysis, they did not consider incorporating velocity information into the system identification process.

Santana, Bim, and Amaral [6] conducted a study on predictive velocity control of a three-phase induction motor, utilizing stator voltage and current as inputs. With the input data, they developed a model capable of estimating the current motor speed and subsequently applied the predictive control technique to this variable.

Thus, in view of this context, the objective of the present work is to apply the system identification methodology to a servomotor for speed estimation based on the Pulse Width Modulation (PWM) signal applied to its input. Section 2 will present the methodological approach utilized. In Section 3, the obtained results, as well as the characteristics of the derived model, will be presented. Finally, in Section 4, conclusions will be drawn concerning the work conducted.

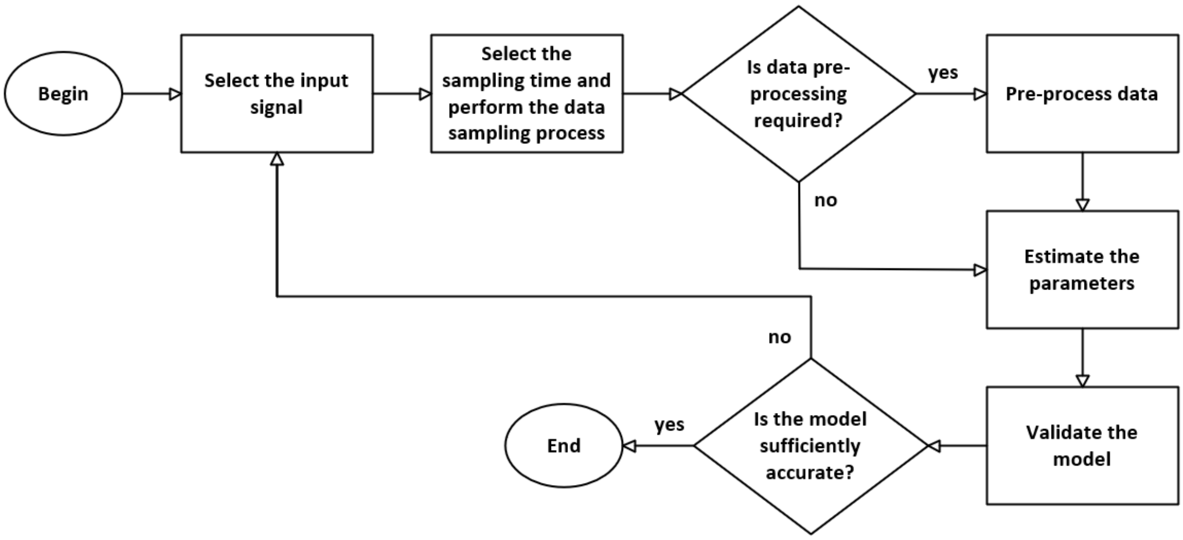
## 2. METHODOLOGY

To carry out this work, the Dynamixel MX-106 servomotor was used. This servomotor has a software, called Dynamixel Wizard, responsible for making the communication interface between it and the computer. Through this software, a previous analysis of the output variables available in the program was made.

To guide the identification process of the system in question, the methodology previously proposed by [7] was adopted in an adapted form, as shown in Figure 1.

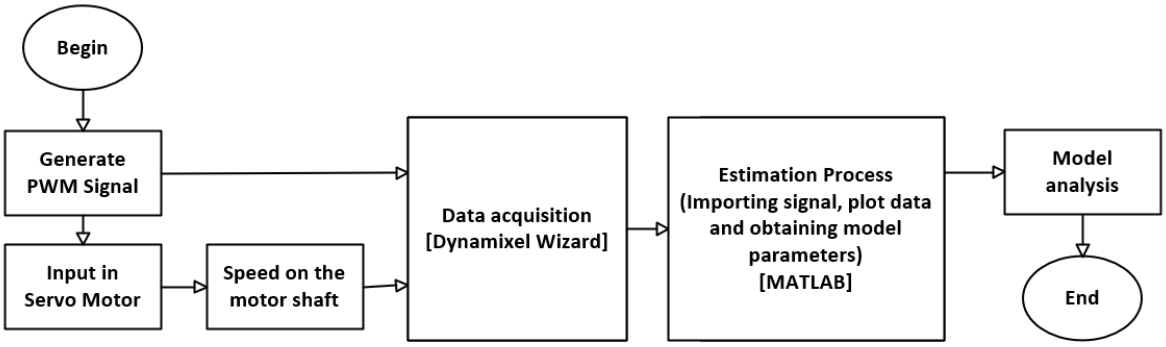
In the step of choosing the input signal, it was found that Dynamixel Wizard provides, for many variables, their present value and their desired value, i.e. their set-point. Thus, the reference values were discarded from the analysis since they can vary instantaneously and do not represent the system transient. Thus, the quantities measured were verified, such as PWM signal, speed, load, and current. The load and current quantities were then discarded, since in the face of the change in the PWM signal, they reflected only the transient of the setpoint change, and in the permanent regime, they remained at approximately constant levels. Thus, PWM was chosen as the input signal and speed as the output, determined beforehand as the signal of interest.

Figure 1. Methodology for system identification [7].




The acquired data were imported into MATLAB software and different models were generated and analyzed to simulate the behavior of the real system, as will be discussed in detail in the following section. Thus, Figure 2 presents a flowchart of the path taken to perform the proposed experiment. As can be seen, the PWM signal is sent to the servomotor, which produces a speed on its axis depending on the received signal. Both signals are then recorded by the Dynamixel Wizard, thus constituting the dataset of the experiment. After that, the data was imported into MATLAB to perform more detailed analysis and subsequently obtain the desired mathematical model.

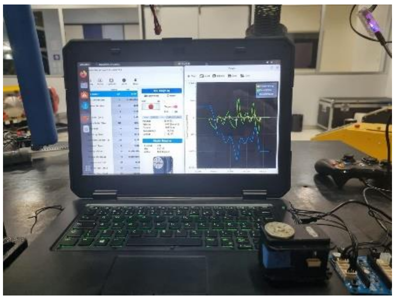
Figure 2. Experiment flowchart and data acquisition.



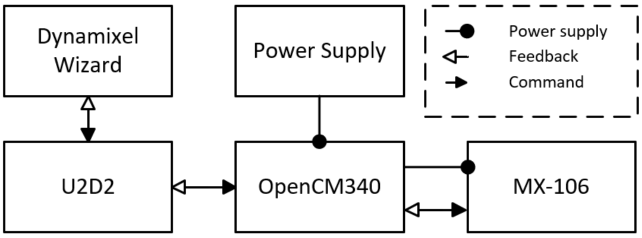
The setup illustrated in Figure 3 was adopted for the experiment, which demonstrates the arrangement of the devices and the operation of the system. This consists of receiving information from the computer, through the U2D2 board, which translates these signals to the motor. The OpenCM340 board is responsible for connecting the motor to the power supply and the communication board.

Figure 3. Setup used for the experiments. (a) arrangement of components (b) signal flow direction.

(a)

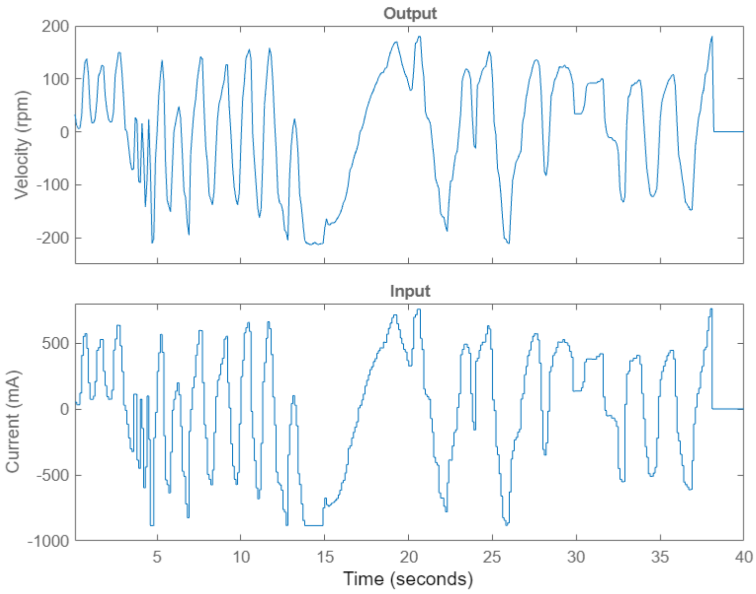


(b)




According to the methodology employed in this study, the first step for system identification is the selection of the input signal. In this work, a random behavior current signal was chosen as the input. This input signal, along with the corresponding output signal obtained, can be observed in Figure 4. These data were separated into two sets, with 50% allocated for both model estimation and validation stages. Moreover, a sampling rate of 100 milliseconds was employed.

Figure 4. Experimental data.



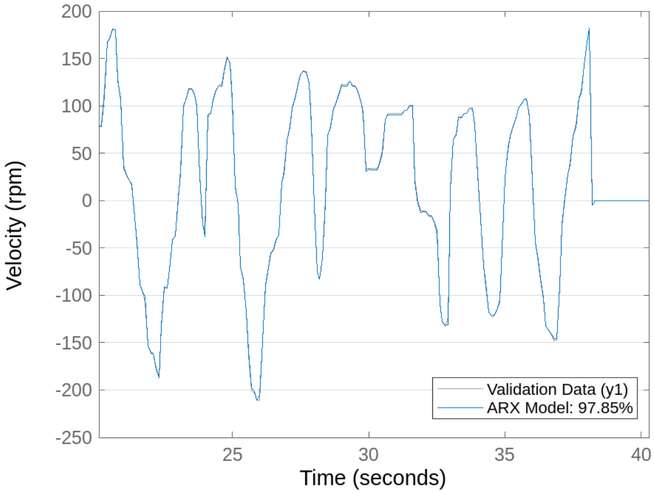
## 3. RESULTS AND DISCUSSION

In order to estimate the required parameters, the MATLAB System Identification Toolbox was employed, and the ARX model was selected as the foundation for modeling, using first order for each polynomial term. Consequently, it was possible to obtain the model for the system presented in Equation 1.

$$Y(z) = \frac{0.2448\, z^{-1}}{1 + 0.02607\, z^{-1}}\, U(z) \tag{1}$$

To validate the obtained model, the input signal from the validation dataset shown in Figure 4 was applied to it. Consequently, the simulated output of the model was compared to the measured output of the physical system, and the fit of the estimated model to the validation dataset (illustrated in Figure 5) was assessed. The result obtained using the fitting equation provided in (1) indicates that the identified model could reproduce an output signal with 97.85% similarity to the actual system. Hence, it can be affirmed that the model closely approximates the real behavior of the system.

Figure 5. Comparison of the output signal between the real system and the model given a random input.

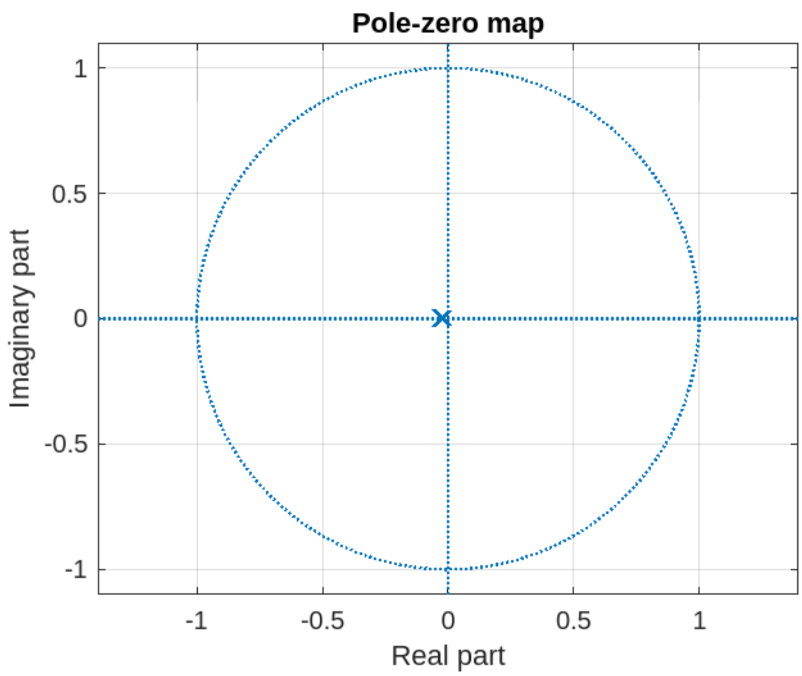



The analysis of the identified system, representing a motor with voltage as input and speed as output, reveals a pole extremely close to the origin in the poles and zeros map in the Z-plane (Figure 6). This indicates a rapid response of the motor to variations in input voltage, which is crucial in speed control applications. The proximity of the pole to the origin suggests stable system behavior, an important aspect to ensure consistent performance and minimize unwanted oscillations. These characteristics underscore the suitability of the identified model for practical applications in motor control systems, where fast response is fundamental for controlled motor performance.

$$y[n] = 0.2448\, u[n-1] - 0.02607\, y[n-1] \tag{2}$$

Equation (1) can be transformed into the discrete-time domain in the form of a difference equation, as shown in Equation (2). Consequently, the obtained mathematical model can be embedded and recursively applied in microprocessor's system.

Figure 6. Discrete pole-zero plane of first order ARX model




## 4. CONCLUSION

The present article introduced a mathematical model obtained through dynamic system identification techniques, aimed at estimating the velocity of a Dynamixel MX-106 servomotor based on a PWM signal applied to its input.

By utilizing a randomly varying PWM voltage signal, it was possible to estimate a first order ARX model. The model was validated using another random signal applied to both the physical system and the model, resulting in a satisfactory fit of 97.85%.

The methodology employed demonstrated the successful development of a model capable of simulating the behavior of the physical system, thus serving as a virtual sensor, i.e., replacing a sensor with a mathematical model.

For future research, it is advisable to apply this model to more complex systems. The obtained results only consider an unloaded servomotor and do not account for the coupling effects of loads. It is also feasible to conduct a comparative analysis between the ARX model and alternative models, such as ARMAX and nonlinear models.

**Acknowledgments**

The authors would like to thank the Robotics and Autonomous Systems Laboratory of SENAI CIMATEC for the support provided and for the availability of all the resources necessary to carry out this project.

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