Dynamic Model and Control of Electroactive Polymer Actuators

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ABSTRACT

The aim of the paper is to describe an integrated approach for modeling the dynamic behavior of actuation systems based on electroactive polymer actuators. The mathematical analysis of the system in order to develop the dynamic model is difficult in this case because of the unknown parameters within governing equations, and therefore a new approach is presented. Thus, an actuation system is considered, and its behavior is determined using Matlab Software, D-space platform and an optical sensor, which analyses the position, velocity and acceleration developed by the actuator. The dynamic model of the system is determined in order to further implement it in a model based control technique. The model is generated, using system identification toolbox within Matlab, based on the input and output (response) of the considered system.

INTRODUCTION

The group of electroactive polymers (EAP) is a family of dissimilar technologies, which are producing actuation based on a large variety of transduction phenomena [3]. As the demand for new actuators with better actuation characteristics and smaller sizes increases, the research activity for this type of unconventional actuators, but also on shape memory alloys, piezoelectric materials, gains big amplitude. For this research electroactive polymers in form of ionic polymer metal composite (IPMC) structures are considered.

IPMC, as a subclass of wet EAP actuators, also referred as 'artificial muscles', are composite structures made of ion exchanging membranes (Nafion, Flemion, Aciplex) and thin layers of metal (Au, Pt)[3][4]. As the most important application field of IPMC actuators is robotics, controlling such actuators presents a significant importance. Their dynamic behavior is studied using an integrated approach in order to generate the model of the considered actuator. Further, a model based control technique is implemented using the previous developed model through system identification method.

EXPERIMENTAL STAND AND METHODOLOGY

As presented in figure 1, the experimental stand for studying the dynamic behavior of actuation systems based on electroactive polymer actuators is compound of:
- The physical system: - IPMC actuator;
The identification process is done by stimulating the system with a step, sinusoidal or random signal and observing the input versus output of the system during a certain period of time, in correlation with the phenomena which underlies the actuation process. The next step involves choosing an appropriate form of the transfer function which will describe the system's behavior. After the model was identified using System identification toolbox within Matlab Software, the model is tested and if inadequate, the methodology described above is repeated until the new obtained model can be validated.

The module based on electroactive polymer as IPMC structure (30X10X0.5mm) and the optical sensor used for measurement are presented in figure 2

In order to activate the IPMC structure using DS 1104 Board, the electrical mounting presented in figure 3 was developed using power transistor NPN BD681 with $I_{C_{max}}=6A$ and one electrical resistance of $R_B=360\Omega$. The base of the transistor is coupled using $R_B$ resistance directly to the DSP_PWM1 port of the control board. The optical sensor which analyses the displacement of the actuator is attached to the ADC 1 port of the control board,
after the response of the sensor was adapted from current response (4-20mA)[8] to voltage response (0..10V) according to the needs of the control board within the stand [9].

EXPERIMENTAL RESULTS

The first step before the data acquisition process is to implement the Simulink model presented in figure 4 on the data acquisition board in order to activate the IPMC actuator through the power transistor used. The same model allows data to be acquisitioned. Thus, the upper branch of the model represents the activation of the considered actuator using a PWM signal with a varying the duty cycle, while the lower branch of the model deals with the component which is responsible with the data acquisition and processing from the implemented optical sensor, as the voltage from the sensor is converted in displacement, in velocity and acceleration by deriving once respective twice the acceleration.

Figure 5 presents the interface developed in Control Desk, with the scope of viewing and recording data from the system. The interface permits displaying the command signal and the response of the system in accordance with it, but also modifying the signal used to activate the actuator. The signals used for system identification are presented in the lower
part of the figure 5 where the input of the system is represented with green and the response -displacement, velocity and acceleration – with red color.

![Figure 5: Data sets used for identification process](image)

Within the experiment, there were identified three models (figure 6a - P3DZ, arxqs and n4s2), being different concerning the form of the transfer function adopted for each of the models, but also on the resemblance factor with the measured output.

![Figure 6: System identification toolbox with generated models.](image)

Matlab software permits evaluating the quality of the obtained models by comparing the response of the model with the data set used for identification \[10\]. The obtained results are presented in figure 6 b. The graphs presented in figure 6 c and d are representing the step
and frequency response of the three models. The graphs presented are the evaluation
criteria for choosing the model with the behavior closest to reality.
The validated model for a further model based control for the IPMC actuator is P3DZ
function, with three poles and one zero, in this case the resemblance with the real system is
85.97%.
The validated transfer function is given by G(s):
\[ G(s) = \frac{1 + T_d s}{(1 + T_{p1} s)(1 + T_{p2} s)(1 + T_{p3} s)} \exp(T_d s) \]  
(1)

with: \( K_p = 30.372, T_{p1} = 39.003, T_{p2} = 0.2424, T_{p3} = 0.43956, T_d = 0, T_z = -1.7737 \)
Loss function: 0.0104481 s/ FPE 0.0108646

The parameters that are defining the transfer function represent real aspects within
the real system behavior, more exactly:
\( K_p \) - static gain;
\( T_d \) - input-output delay;
\( T_p \) - time constant.

In order to simulate the model's response to a PID controller, a Simulink model was
developed, model presented in figure 7. A discrete PID controller was used because the
input for the previous generated model is represented by PWM duty cycle, with values in
[0..1]. Imposing constraints on the response of the model, such as rise time (1sec), settling
time (7 sec) and steady state error (<1mm), the obtained parameters for the PID controller
are: \( K_p = 1, K_i = 1, K_d = 1 \).

Figure 7: Step and sine wave response of obtained P3DZ model
CONCLUSIONS

The article succeeded to present an integrated approach to determine the dynamical model of actuation systems based on IPMC actuators. The advantage of the method is that despite the complex equations which are underlying the actuation process, the behavior of the actuator can be easily modeled and described. Using the model identification method, the model is automatically generated by Matlab software, the user only has to record input signal and the response of the considered system and to analyze the system in order to generate and validate a model [2]. The models obtained with system identification toolbox are offering well suited and easy to apply solutions for simulations, predictions and control system design of complex systems.

The actuation characteristics obtained during the experimental research are concluding that the stroke of the IPMC actuator reaches 2mm, the time response 5 seconds, while the maximum speed and acceleration reached at 1.5mm/s respective 10mm/s², characteristics which are well suited for novel robotics or biomedical applications.

REFERENCES


