Identification of Ionic Polymer Metal Composite Actuator Using State-Dependent Parameter Method

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Abstract

Ionic polymer metal composite (IPMC) actuator is a group of electro-active polymers (EAPs) which bend in response to a relatively low electrical voltage because of the motion of cations in the polymer network. IPMC has a wide range of applications in robotics, biomedical devices and artificial muscles. The modeling of the IPMC actuator is a multi-physics task as it involves the electricity, chemistry, dynamics and control fields. Due to its complexity and nonlinearity, IPMC modeling is difficult in terms of mathematics and its behavior is still not fully agreed upon by researchers. This paper presents a novel discrete-time model with state-dependent parameters (SDP) for identification of the nonlinear response of an IPMC actuator. A single-input single-output nonlinear identification algorithm is formulated and demonstrated for an IPMC actuator that exhibits both soft and hard nonlinearities. The non-linear characteristics of the identified system are represented with coefficients which are a function of past inputs and outputs. The proposed modeling approach is validated using an existing model and shows exact representation of the non-linear behavior of the IPMC actuator.

Keywords:
Ionic polymer metal composite (IPMC)
Electro-active polymer (EAP)
Identification
State-dependent parameter (SDP)

References:


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Introduction

The modeling of the IPMC actuator is a multi-physics task as it involves the electricity, chemistry, dynamics and control fields. Due to its complexity and nonlinearity, IPMC modeling is difficult in terms of mathematics and its behavior is still not fully agreed upon by researchers. This paper presents a novel discrete-time model with state-dependent parameters (SDP) for identification of the nonlinear response of an IPMC actuator. A single-input single-output nonlinear identification algorithm is formulated and demonstrated for an IPMC actuator that exhibits both soft and hard nonlinearities. The non-linear characteristics of the identified system are represented with coefficients which are a function of the input and output states. Following the SDP algorithm, the model is identified from input–output data to represent the model parameters as functions of past inputs and outputs. The proposed modeling approach is validated using an existing model and shows exact representation of the non-linear behavior of the IPMC actuator.
2- State Dependent Parameters (SDP)

The effect of applying voltage to the IPMC actuator, 

1- Back relaxation

Fig. 1 The effect of applying voltage to the IPMC actuator

Materials and Methods

The IPMCs were fabricated from a polyvinylidene fluoride (PVDF) polymer film that was cast into shape and then chemically treated to create charged polyelectrolyte layers. The actuator was excited by applying a DC voltage to the terminals, resulting in a deformation of the material. The deformation was measured using a displacement sensor, and the resulting force was calculated using the equation of motion for a simple harmonic oscillator. The results showed that the IPMC actuator could be used for various applications, such as robotic manipulators and artificial muscles.

1- Back relaxation
2- State Dependent Parameters (SDP)
روش شناسایی پارامترهای وابسته به متغیر حالت

همراه با مشخص کردن عملکرد و امکان بازماندن، اگر پارامترها توانایی نسبی مدل تطبیقی بزرگی را داشته باشند، آنگاه از پارامترهای مناسب مدل کاربردی می‌تواند مورد استفاده قرار گیرد. به روش تحقیقی یکی از روش‌های مدل اینکار در روش‌های انجام شده است، به‌طوری‌که مدل را با هر تاریکی مانند: محدوده عملکردی مدل را به‌طور کامل رفع نماید.

جدول 1. معیار وانک برای انتخاب عدد متغیر جفت شناسایی سیستم

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روش انتخاب متغیر

buah به یک توجه به متغیرهای در رابطه 1  با نظر به مدل‌های وابسته به متغیر، مدل‌های عملکردی مدل را به‌طور کامل رفع نماید.

\[
\theta(k) = \{\alpha_1(\Phi_T(k)), \alpha_2(\Phi_T(k)), \ldots, \alpha_n(\Phi_T(k)) \}^T
\]

\[
\beta(k) = \{\beta_1(\Phi_T(k)), \beta_2(\Phi_T(k)), \ldots, \beta_n(\Phi_T(k)) \}^T
\]

(3) در رابطه 3، می‌تواند با توجه به متغیرهای وابسته به متغیر، مدل‌های عملکردی مدل را به‌طور کامل رفع نماید.

\[
\Phi_T(k) = \begin{bmatrix}
\phi(k-1) \\
\phi(k-2) \\
\phi(k-3) \\
\end{bmatrix}
\]

(2) در رابطه 2، می‌تواند با توجه به متغیرهای وابسته به متغیر، مدل‌های عملکردی مدل را به‌طور کامل رفع نماید.
\begin{align*}
\frac{\text{d}^2 x}{\text{d}t^2} + \beta_1 \frac{\text{d} x}{\text{d} t} + \beta_0 x &= 0.0182 \\
0.0391 T^2 + 0.182 T + 0.0198 &= 0
\end{align*}

The main output and sorted output of the system are:

\begin{align*}
y(k) &= \alpha_1 \Phi(k)^T y(k-1) + \alpha_2 \Phi(k)^T y(k-2) \\
&\quad + \beta_1 \Phi(k)^T u(k-1) + \beta_0 \Phi(k)^T u(k-2) + \epsilon(k)
\end{align*}

\begin{align*}
\hat{\theta}(k|k-1) &= A \hat{\theta}(k-1) \\
P(k|k-1) &= A P(k-1) A^T + D Q_{\text{wv}} D^T
\end{align*}

\begin{align*}
\hat{\theta}(k) &= \hat{\theta}(k|k-1) + g(k) \{ y(k) - \Phi(k)^T \hat{\theta}(k|k-1) \} \\
g(k) &= P(k|k-1) \Phi(k)^T [1 + \Phi(k)p(k|k-1) \Phi(k)]^{-1} \\
P(k) &= P(k|k-1) - g(k) \Phi(k)^T P(k|k-1) \Phi(k) \\
P^*(k) &= \delta^2 P(k)
\end{align*}

\begin{align*}
\hat{\theta}(k|N) &= \hat{\theta}(k) - P^*(k) A^T \lambda(k) \\
\lambda(k|1-N) &= P^*(k) A^T [\Phi(k) \hat{\theta}(k|k-1)]^{-1} \\
&\quad - D^T \{ \Phi(k)^T [1 + \Phi(k)p(k|k-1) \Phi(k)]^{-1} \}
\end{align*}

\begin{align*}
P^*(k) &= P^*(k) + P^*(k) A P^*(k) [P^*(k)+1]^{-1} \\
&\quad \left[ P(k+1|N) - P^*(k+1|k) P^*(k+1|k)^{-1} A P^*(k) \right]
\end{align*}
Hall by a different frequency input signal. A typical output signal is shown in (Fig. 5) and (Fig. 6).

Fig. 6 Changes coefficient input values according to the input white noise signal.

Fig. 7 Identification of the system response by the SDP method respect to the Chirp input signal.

Fig. 5 Variations of the output coefficients according to the input white noise signal.

Identification of the system response by SDP method based on the white noise input signal.

1- Standard Error Bounds (\( SE = \sqrt{\sigma^2 + 2N} \))
Fig. 10 Identification the system response by the SDP method respect to a Random input signal

Fig. 8 Identification the system response by the SDP method respect to a Square input signal

Fig. 9 Identification the system response by the SDP method respect to a Normal Repeating Sequence input signal

In order to identify the system response by the SDP method, the following steps are taken:

1. The system is excited by a random or square or normal repeating sequence input signal.
2. The system response is measured by the displacement and voltage sensors.
3. The data is collected and analyzed using the SDP method.
4. The identified system response is compared with the theoretical response.

The identified system response is then used to design a control system for the system.

The identified system response is also used to validate the model of the system.

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