Robust Control for Shape Memory Alloy Micro-Actuators Based Flap Positioning System

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Abstract—In this paper, the control approach for a flap positioning based shape memory alloy micro-actuator is addressed. The challenge here are to model the saturation-type hysteresis in the shape memory alloy actuator, and design the controller to mitigate the effect of hysteresis and ensure the system performance. In this paper, the saturation-type hysteresis nonlinearities are represented by the generalized Prandtl-Ishlinskii model. Considering the lag effect between the temperature and the control input, the proposed robust control can stabilize the closed-loop system and ensure the accurate rotation of the flap to the desired angle without the construction of the hysteresis inverse. The effectiveness of the proposed control approach is demonstrated through a simulation example.

I. INTRODUCTION

Smart actuators, such as piezoceramic, magnetostrictive, and shape memory alloy (SMA) actuators have been widely utilized in micropositioning applications. Compared with other actuators, SMA actuators have large deformation and keep relatively good position recovery ability, and have been adopted to ensure the fast response of the positioning system, such as in small-scale flight surface actuation. However, the hysteresis existing in the SMA actuator limits the accuracy of the system and degrades system performance. In order to mitigate the effects caused by the hysteretic nonlinearities in SMA actuators, the development of control approaches for the positioning system with the SMA actuator is a challenging task. Focusing on this challenge, choosing a hysteresis model to describe the hysteresis phenomena in SMA actuators is a primary step for controller design.

SMA actuator can induce large force or displacements when the temperature is changed. The force/displacement-temperature relationship existing in the SMA actuator has a strong hysteresis nonlinearities, which exhibits the saturation-type property [8]. So far, numerous hysteresis models have been used to express the hysteresis phenomena in the SMA actuator. Usually, the hysteresis models are classified as special hysteresis models addressing the SMA actuator, such as Tanaka’s constitutive model [22], Brinson SMA model [3], and the general hysteresis models [2][9][23], such as Preisach model, Krasnoselski and Prokrovskii’s (KP) model and Prandtl-Ishlinskii (PI) model. These general operator-based models have been adopted for the modeling of SMA actuators [1][6][21]. The advantage of these general hysteresis models is to reflect the thermometrical hysteretic behavior of SMA actuators exactly and can be combined with the control approaches to improve the performance of the positioning systems.

By utilizing these hysteresis models, the control of smart material actuators based positioning systems has attracted significant attention [17][18], and many efforts have been developed to improve the system positioning precision [4][5][19]. In [12][13], a quasipassivity-based robust control approach for SMA actuators based flap positioning was proposed. In [16], an inversion-based PID controller was developed to track a desired torque. In [21], an adaptive inverse control of hysteresis for smart materials actuators was established. These control approaches usually address two main tasks. One is to compensate the effects caused by the hysteresis nonlinearities in the SMA actuators, such as establishing the inverse hysteresis model [21] or treating the actuator as a time-delay system [14]. Another is to ensure the stability of the close-loop control system [12][16][24].

In this paper, a robust control is proposed for a SMA actuators based flap positioning system, where the thermometrical hysteretic behavior is represented by a generalized Prandtl-Ishlinskii model [1]. An experiment has been conducted to validate the accuracy of this model. Without the construction of the hysteresis inverse and considering the dynamics of flap, the proposed robust control algorithm ensures stability of the closed-loop positioning system and the flap angle can follow a specified trajectory with a desired precision.

II. SMA ACTUATOR BASED FLAP POSITIONING SYSTEM

In this paper, a flap positioning system based on an antagonist-type SMA micro-actuator is addressed. The structure of the positioning system is shown in Fig. 1. For SMA actuators, there are three configurations: One-way SMA actuators [11], bias-spring SMA actuators [16], and antagonist actuators (differential actuators) [8][11]. The antagonist actuators consist of two SMA wires complementing each other. When one of the wires is heated, it contracts and induces tension in the other SMA wire and the pulley is displaced. When the second wire is heated it recovers the strain and moves the pulley in the opposite direction. The position of the pulley is determined by heating and cooling the two SWA wires. The purpose of the system is to force the rotation angle of the pulley $\theta$ to follow the desired trajectory $\theta_d$.

In order to analyze the motion of the actuator, as in [12], one assumption for the SMA fibers is given.
Assumption 1: When the SMA actuator is heated, the force generated by SMA actuator can be decomposed in two items: the stiffness of SMA actuator and the contraction force of SMA actuator.

- For the stiffness of SMA actuator $f_s$, the change in the opposing force $\delta f_s$ is linear with the change of the angle of rotation $\delta \theta$, that is $\delta f_s = k_s \delta \theta$, where $k_s$ is a constant depending on the physical parameters of the SMA actuator.
- For the contraction force of SMA actuator $f_c$, which is generated by the change of the temperature, that is $\delta f_c = k_c H(T)$, where $H(T)$ is a nonlinear function to represent the hysteresis properties in the SMA actuator and $k_c$ is a constant depending on the physical parameters of the SMA actuator.

![Fig. 1. Structure of SMA actuator based flap positioning system.](image)

Then, the motion of the SMA actuator based flap position system can be described as

$$J \ddot{\theta} + \rho \dot{\theta} + k_a \nu^2 \theta = k_c H(T(t)) - M_a$$

(1)

where $2r$ is diameter of the pulley, $\theta$ is the rotation angle of the pulley, $J$ is the moment of inertia of the pulley and the flap, $\rho$ is a damping coefficient and $M_a$ is the aerodynamic moment applied on the flap and is assumed to be bounded $|M_a| \leq \Gamma$.

III. SMA ACTUATOR MODELLING

A. SMA hysteresis characteristics

The hysteresis existing in the SMA is a phase transformation from the austenite phase to the martensite phase, or vice-versa. As shown Fig. 2, there are four transformation temperatures as shown in Table I. It is obvious that the input-output characteristics of the shape memory alloy has strong saturation-type hysteresis properties. Considering the saturation-type hysteresis, a generalized Prandtl-Ishlinskii model is adopted in this paper, which is based on the generalized play hysteresis operator [1]. By choosing the proper density function, the input function and the envelop functions, the generalized prandtl-Ishlinskii model can describe the saturation-type hysteresis in the SMA actuators accurately. In this section, the generalized Prandtl-Ishlinskii model is introduced briefly.

![Fig. 2. Transformation temperatures of shape memory alloys](image)

B. Generalized Play Hysteresis Operator

The generalized Prandtl-Ishlinskii model is an operator-based hysteresis model, and it has integral models whose kernel involves an infinite number of hysteretic operator, which can describe the hysteresis shapes accurately. As a extension of the play or stop operators [9][23], the choice of the envelop functions in the generalized play operator makes it possible to represent the saturation-type hysteresis nonlinearities.

As shown in Fig. 3, the continuous envelop functions $\gamma_l$ and $\gamma_r$ [2][23] are used to describe the curves, satisfying $\gamma_l < \gamma_r$. An increase and decrease in input $v(t)$ will cause the output $w(t)$ to increase and decrease, respectively, along the curve $\gamma_l$ and $\gamma_r$ resulting in complex hysteresis loops. The minor loops of the input $v$ and the output $w$ are bounded by the curves $\gamma_l$ and $\gamma_r$.

![Fig. 3. Generalized Play Operator](image)

Analytically, suppose $C_m[0, t_E]$ is the space of piecewise monotone continuous functions, and the generalized play operator $F^\gamma_{ir}[v](t)$ for any input $v(t) = C_m[0, t_E]$ and the threshold $r$ is defined by [2][23]

$$F^\gamma_{ir}[v](0) = f_{ir}(v(0), 0) = w(0)$$

$$F^\gamma_{ir}[v](t) = f_{ir}(v(t), F^\gamma_{ir}[v](t_i)),$$

for $t_i < t \leq t_{i+1}$ and $0 \leq i \leq N - 1$
where \( f_{lr}(v, w) = \max(\gamma_l(v) - r, \min(\gamma_r(v) + r, w)) \).

C. Generalized Prandtl-Ishlinskii Model

The generalized Prandtl-Ishlinskii model can be formulated upon integrating the generalized play operator \( F_{lr}^t[v](t) \) to yield output \( w(t) \) as

\[
w(t) = h(v(t)) + \int_0^R p(r) F_{lr}^t[v](t)dr \tag{3}
\]

where \( h \) is a non-decreasing Lipschitz continuous function, and it is treated as the input function; \( p(r) \) is a given density function, satisfying \( p(r) \geq 0 \) and vanishing for large values of \( r \). The density function can be expected to be identified from experimental data. \( R \) is a constant so that the density function \( p(r) \) vanishes for large value of \( R \).

D. Generalized Prandtl-Ishlinskii Model for SMA Actuator

As mentioned in the literature [15], the hysteresis phenomena in the SMA actuators are the transformation between the temperature and the output torque or displacement, which could be represented by the generalized Prandtl-Ishlinskii model as follows

\[
H(\tilde{T}(t)) = h(\tilde{T}(t)) + \int_0^R p(r) F_{lr}^t[\tilde{T}](t)dr \tag{4}
\]

However, the actual temperature in the system cannot be measured in real time and the SMA actuators are driven by the current or voltage as the control input, which is obtained by using a pulse width modulation (PWM) driver. The relationship between a duty ratio \( v \) and a temperature \( \tilde{T} \) is a first-order system [12][15][20] given by

\[
\frac{d\tilde{T}}{dt} \approx -\frac{4h}{\rho cd_0} \tilde{T} + \frac{4}{\rho c \pi d_0^2 L_0} v \tag{5}
\]

where \( \rho \) is the mass density of the SMA wire; \( c \) is the specific heat of the SMA wire; \( L_0 \) is the undeformed SMA wire length in 100% high temperature austenite phase; \( d_0 \) is the cross-sectional diameter of underformed SMA; \( h \) is the convection heat transfer coefficient.

Considering the lag effect between the temperature and the duty ratio of PWM driver [15], the hysteresis in the SMA actuators is re-defined in (6), where the control input is the duty ratio of the PWM driver the output is the displacement or the force,

\[
H(v(t)) = \gamma_0 v(t) + \int_0^R p(r) F_{lr}^t[v](t)dr + d(t) \tag{6}
\]

**Remark 1:** For the generalized Prandtl-Ishlinskii model defined in (6), the input function \( h(v(t)) \) is selected as a linear function, not a tangent-hyperbolic function [1]. Since the choices of the envelope functions and the input function are not unique, \( h(v(t)) \) may be chosen as a linear function, which makes it possible for the controller design to ensure the system performance. \( d(t) \) can be treated as a disturbance item, which includes the error caused by the lag effect and the measured error. In this paper, \( d(t) \) is assumed to be bounded. The accuracy of this model expression is validated in the next subsection.

E. Parameters Identification of SMA Actuator

The identification experiment is conducted to validate the generalized Prandtl-Ishlinskii model defined in (6). The SMA actuator identification platform is introduced in [13] and is composed of a) a digital board; b) the power electronics and the analog electronic devices; c) two SMA wires; d) micro-flow effector with compliant link. The input to the system is the voltage reference trajectory \( v \) (volt) which is a chirp voltage magnitude \( V_n \) in \([0.3Hz, 1Hz]\). The output of the system is the actuator displacement \( d_m \) (mm). The structure of the platform is shown in Fig. 4, and the hysteresis curve existing in the SMA actuators is shown in Fig. 5.

![Fig. 4. The experimental platform of hysteresis identification](image_url)

![Fig. 5. The hysteresis curve existing in the SMA actuator](image_url)

The generalized Prandtl-Ishlinskii model (6) parameters are identified by using the measured data between input voltage and the output displacement. Using the minimization of an error squared function introduced in [1], the density function is selected as \( p(r) = 0.3542e^{-0.0018r} \), where \( R = 5 \), \( q = 0.164 \), and the envelop functions \( \gamma_l \) and \( \gamma_r \) are selected as \( \gamma_l(v) = 2.3164tanh(v - 0.2) \) and \( \gamma_r(v) = 2.3164tanh(v + 0.98) \).

The output displacements from the measured data and the generalized Prandtl-Ishlinskii hysteresis model are shown in Fig. 6. According to the comparison results, the generalized Prandtl-Ishlinskii model (6) can match the characteristics of the SMA actuators. However, there is still the error between the experiment data and the output of the generalized Prandtl-Ishlinskii model. The error can be treated as a bounded disturbance and will be handled in the control approach.

IV. CONTROLLER DESIGN

Focusing on the SMA actuator based flap positioning system (1), the robust control approach is addressed in this section. The closed-loop control structure is shown in Fig. 7. Therein, the hysteresis nonlinearity in the SMA actuators is represented by the generalized Prandtl-Ishlinskii model defined in (6). The control objective is to design a robust controller to make the flap angle \( \theta(t) \) to follow a specified
desired trajectory $\theta_d(t)$ and ensure the stability of the closed-loop positioning system.

![Image of a closed-loop flap positioning system control structure.](image-url)

Fig. 7. The closed-loop flap positioning system control structure.

For the the flap positioning system (1), define $\theta_1 = \theta$ and $\theta_2 = \dot{\theta}$, then the system can be re-written as

$$\begin{align*}
\theta_2 &= \dot{\theta}_1, \\
\dot{\theta}_2 &= -\frac{\rho}{J} \theta_2 - \frac{k_x r^2}{J} \theta_1 + \frac{k_x r}{J} H(t) - \frac{M_d}{J}
\end{align*}$$

By utilizing the generalized Prandtl-Ishlinskii model to describe the hysteresis in the SMA actuator, we have

$$\begin{align*}
\theta_2 &= \dot{\theta}_1, \\
\dot{\theta}_2 &= -\frac{\rho}{J} \theta_2 - \frac{k_x r^2}{J} \theta_1 + \frac{k_x r}{J} v(t) + \frac{M_d}{J}
\end{align*}$$

For convenience, we define $\psi(t) = \frac{k_x}{J} d(t) - \frac{M_d}{J}$. According to the foregoing analysis, $d(t)$ and $M_d$ are bounded, then it can be concluded that $\psi(t)$ is bounded and $\Psi$ is employed as the boundedness of $\psi(t)$.

In order to present the developed control laws, the following assumptions are required:

**Assumption 2:** The desired trajectory $\theta_d = [\theta_d, \dot{\theta}_d]^T$ is continuous. Furthermore, $[\theta_d^T, \dot{\theta}_d^T] \in \Omega_d \subset R^2$ with $\Omega_d$ being a compact set.

**Assumption 3:** For the generalized Prandtl-Ishlinskii hysteresis model (6), the nonlinear item represented by the generalized play operator $\int_0^R p(r) F_{\tau r}^[-][v](t) dr$ satisfies the following property:

$$\eta(v - v_0) \leq \int_0^R p(r) F_{\tau r}^[-][v](t) dr \leq \eta(v + v_0)$$

where $\eta$ is a positive constant and $v_0 \geq 0$.

**Assumption 4:** There exists a known constant $q_{\text{min}}$, such that $q \geq q_{\text{min}}$.

**Remark 2:** Assumption 2 is common for the desired angle signals. For the saturation-type hysteresis nonlinearities existing in the SMA actuators, it is reasonable to set the known linear functions as the boundedness of the nonlinear part in Assumption 3. For Assumption 4, it is not difficult to get the minimum value based on the identification experimental data.

In order to design the robust controller, the tracking error $\hat{\theta}$ is defined as

$$\hat{\theta} = \theta - \theta_d$$

then a filtered tracking error is expressed as

$$s(t) = [\lambda \ 1] \begin{bmatrix} \dot{\theta}_1 \\ \dot{\theta}_2 \end{bmatrix}, \ \lambda > 0$$

Usually, a tuning error $s_c(t)$ is utilized as,

$$s_c = s - \varepsilon \text{sat}(\frac{s}{\varepsilon})$$

where $\varepsilon > 0$ is a constant and $\text{sat}(\cdot)$ is the saturation function. The tuning error $s_c$ disappears when $|s| \leq \varepsilon$.

According to the definitions in (8) and (11), the following equality can be obtained that

$$\dot{s}(t) = \lambda(\dot{\theta}_1 - \dot{\theta}_d) + (\dot{\theta}_2 - \dot{\theta}_d)$$

$$= \lambda(\dot{\theta}_1 - \dot{\theta}_d) - \frac{\rho}{J} \theta_2 - \frac{k_x r^2}{J} \theta_1 + \frac{k_x r}{J} q\psi(t) + \frac{k_x r}{J} \int_0^R p(r) F_{\tau r}^[-][v](t) dr + \psi(t) - \dot{\theta}_d$$

In order to present the developed control law, the following definition is required: $\Psi = \Psi - \tilde{\Psi}$, where $\Psi$ is the estimation of $\tilde{\Psi}$. Then, the control law is given by

$$v = \text{sgn}(s_c)(\phi(\theta, t) - v_0)$$

where

$$\phi(\theta, t) = \frac{k_x}{J} (-\beta)(\lambda(\dot{\theta}_1 - \dot{\theta}_d)) + \frac{k_x r^2}{J} \theta_1 + \frac{\rho}{J} \theta_2 + \dot{\theta}_d + \frac{1}{\beta} \tilde{\Psi}$$

and the parameter estimation law for $\tilde{\Psi}$ is given by

$$\dot{\tilde{\Psi}} = \kappa|s_c|$$

where $\beta$ and $\kappa$ are positive constants.

**Theorem 1:** For the SMA actuator based flap positioning system described by (1), where the unknown hysteresis existing in the SMA actuator is represented by the generalized Prandtl-Ishlinskii model (6), the robust control law given in (14) and the parameter estimation law given in (16) ensure that all the closed-loop signals are bounded and the flap angle $\theta(t)$ follows a specified desired trajectory $\theta_d(t)$.

**Proof:** To establish global boundedness, the following Lyapunov function candidate can be defined as

$$V(t) = \frac{1}{2} s^2 + \frac{1}{2} \tilde{\Psi}^2$$

(17)
then the differentiating \( V(t) \) with respect to time \( t \) leads to
\[
\dot{V}(t) = \varepsilon s \dot{s} + \frac{1}{\kappa} \tilde{\varphi} \dot{\hat{\varphi}} - \frac{k_r}{j} \varphi \varepsilon (t) \]
(18)
According to the definition of \( s \), it has \( s \dot{s} = \dot{s}^2 \), then we have
\[
s \dot{s} = s_n |\lambda(\dot{\theta} - \dot{\theta}_d)| \frac{k_r}{j} \varphi \varepsilon (t) \]
\[
+ \frac{k_r}{j} \int_0^R p(r) F_{i \varepsilon}^r[v](t) \varphi(t) - \psi(t) - \ddot{\varphi}_d \] 
\[
\leq |s_n| \varphi |\lambda(\dot{\theta} - \dot{\theta}_d)| \]
\[
+ \frac{k_r}{j} \int_0^R p(r) F_{i \varepsilon}^r[v](t) \varphi(t) + |s_n| |\lambda(\dot{\theta} - \dot{\theta}_d)| \]
\[
+ \frac{\rho}{j} |x_2 + \frac{k_r}{j} \varphi \varepsilon (t) + \ddot{\varphi}_d| + |s_n| \varphi \] 
(19)
When \( s_n > 0 \), the control law can be simplified as \( \varphi = \phi(\theta, t) - v_0 \), then the inequality in Assumption 3 can be expressed as
\[
\eta(\phi(\theta, t) - 2v_0) \leq \int_0^R p(r) F_{i \varepsilon}^r[v](t) \varphi(t) \leq \eta(\phi(\theta, t) + 2v_0) 
\]
(20)
Similarly, when \( s_n < 0 \), the control law is \( \varphi = -\phi(\theta, t) + v_0 \), then the following inequality can be obtained
\[
-\eta(\phi(\theta, t) - 2v_0) \leq -\int_0^R p(r) F_{i \varepsilon}^r[v](t) \varphi(t) \leq -\eta(\phi(\theta, t) + 2v_0) 
\]
then we have
\[
\eta(\phi(\theta, t) - 2v_0) \leq -\int_0^R p(r) F_{i \varepsilon}^r[v](t) \varphi(t) \leq \eta(\phi(\theta, t) + 2v_0) 
\]
(21)
According to the above analysis, it can be concluded that
\[
\eta(\phi(\theta, t) - 2v_0) \leq \varphi |\lambda(\dot{\theta} - \dot{\theta}_d)| \frac{k_r}{j} \varphi \varepsilon (t) + |s_n| |\lambda(\dot{\theta} - \dot{\theta}_d)| \]
\[
+ \frac{\rho}{j} |x_2 + \frac{k_r}{j} \varphi \varepsilon (t) + \ddot{\varphi}_d| + |s_n| \varphi \] 
(19)
According to the definition of \( \phi(\theta, t) \), the inequality can be deduced as
\[
s \dot{s} \leq -\beta |s_n| |\lambda(\dot{\theta} - \dot{\theta}_d)| \frac{k_r}{j} \varphi \varepsilon (t) + \frac{\rho}{j} \dot{\varphi} \dot{\hat{\varphi}} + \ddot{\varphi}_d \]
\[
+ \frac{1}{\kappa} \tilde{\varphi} \dot{\hat{\varphi}} \]
\[
+ \frac{k_r}{j} |s_n| qv_0 + |s_n| |\lambda(\dot{\theta} - \dot{\theta}_d)| \]
\[
+ \frac{\rho}{j} \dot{\varphi} \dot{\hat{\varphi}} + \frac{k_r}{j} \varphi \varepsilon (t) + \ddot{\varphi}_d| + |s_n| \varphi \] 
(24)
According to the parameter estimation law in (16) and \( \beta > 1 \), we have \( \dot{V}(t) \leq -\frac{\kappa}{\kappa} s \varphi qv_0 \leq 0 \), then we can conclude that \( (13) \) is bounded, and \( \dot{V}(t) \leq 0 \) for all \( t \). By Barbalat’s lemma \[7\], we can prove that \( \dot{V}(t) \to 0 \), therefore, from (12), it can be shown that \( s_n(t) \to 0 \) as \( t \to \infty \). If the equation \( s(t) = 0 \), the tracking error \( \theta - \dot{\theta}_d \) decays exponentially to zero. If \( \dot{\theta}(t) = 0 \) and \( |s(t)| \leq \varepsilon \), then \( \dot{\theta}(t) \to 0 \) for all \( t \). If \( \dot{\theta}(t) \neq 0 \) and \( |s(t)| \leq \varepsilon \), then \( \dot{\theta}(t) \) will converge to \( \Theta \) within a time-
constant \( 1/\lambda \).

Remark 3: In this paper, the generalized Prandtl-Ishlinskii model is employed to represent the hysteresis characteristics in SMA actuators. Considering the multiplicity of the input function and the envelop functions, the generalized Prandtl-Ishlinskii model could be used to describe the complex hysteresis shapes in other smart material based actuators, such as piezoelectric actuators and magnetostrictive actuators. The control approach proposed in this paper can be extended to other smart materials actuators based positioning systems directly.

V. NUMERICAL SIMULATION
In this section, the effectiveness of the robust controller for the SMA actuators based flap positioning system is validated by the simulation, where the generalized Prandtl-Ishlinskii model is utilized to represent the hysteresis in the SMA actuator, and the parameters have been identified in Section III. Still considering the experiment platform in [12], the position system parameters can be set as: each SMA wire has a total length of 23cm, a diameter of 0.5mm and can be deformed up to 10mm, \( r = 2 \cm \), \( k_s = 8 \), \( k_c = 0.1012 \), the ambient temperature is set as 273K, \( J = 5 \cdot 10^{-5} \text{kg} \cdot \text{m}^2 \), and \( \rho = 0.002 \text{kg} \cdot \text{m}^2 \cdot \text{s}^{-1} \). For the unknown exogenous disturbance is selected as \( M_a = 0.03 \text{N} \cdot \text{m} \).
For the flap positioning system, there are two typical position schedules. One is the set-point regulation and another is sinusoidal signal regulation. In order to show the close-loop system performance, the simulation includes a
set-point regulation $\theta_d = 14.3^\circ$ and a sinusoidal signal $\theta_d = 10\sin(5\pi t)$. Utilizing the control law in (14), the control parameters are set as $\eta_{\text{min}} = 0.15$, $\eta = 0.53$, $\beta = 9.52$, $\lambda = 10$, $\varepsilon = 0.1$, $\kappa = 0.47$, $\Psi(0) = 1$, and $v_0 = 10$. For the set-point regulation, the initial values are set as $\theta_1(0) = 0$ and $\theta_2(0) = 0$, and the tracking error is shown in Fig. 8. For the sinusoidal signal tracking, the initial values are set as $\theta_1(0) = 1$ and $\theta_2(0) = 20$, and the tracking error is shown in Fig. 9.

As shown in Fig. 8 and Fig. 9, the system can reach the desired requirement in less than 0.5 sec and keep the steady-state error less then 1%. The simulation results illustrate the effectiveness of the proposed control algorithm for the position requirement and will provide an effective scheme for the experiment construction.

VI. CONCLUSION

In this paper, a robust control for a SMA actuator based flap positioning system is addressed. Therein, a generalized Prandtl-Ishlinskii model is adopted to describe the saturation-type hysteresis nonlinearities existing in the SMA actuator. Without the construction of the hysteresis inverse, a robust control is designed to stabilize the flap dynamics and ensure the trajectories performance of the closed-loop system. By exploring the characteristics of the generalized Prandtl-Ishlinskii model, this method avoids the complexity to construct a hysteresis inverse and the simulation results validate the effectiveness of the proposed approach.

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