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A Velocity Observer Based on Friction Adaptation

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Abstract— **Control of robotic systems subject to friction phenomena is an important issue since growing demands on accuracy require elimination of friction disturbances. If several models—*e.g.*, friction model, rigid-body dynamics—are required to describe the behavior with high precision, each model requires the knowledge of numerous parameters (perhaps time-varying) as well as an increased number of signals and sensors. In order to tackle this double limitation, an observer is proposed, addressing both the problem of velocity reconstruction and friction estimation in the joint of an inverted pendulum. Firstly, an adaptive two-level velocity observer is defined to reconstruct relevant unmeasured velocities, using estimation of the friction model error. Secondly, the observer is exploited for model-based friction compensation. Capabilities of the algorithm proposed are demonstrated by means of experiments on the Furuta pendulum.**

I. Introduction

In many robotic systems, the impact of friction on motion is non-negligible. Apart from being the origin of accuracy problems, friction may induce unwanted limit cycles around desired set-points. In particular, this is the case for robot control with significant dynamics, such as the Furuta inverted pendulum considered in this paper. The control of such a robot for an accurate stabilization requires on one hand, the knowledge of velocities in each of the joints (often unavailable by a direct measure) and, on the other hand, the compensation of friction effects. Velocity estimation in the joints of such a robot cannot be based on a simple numerical derivative of the recorded position signal coupled with a low-pass filter. As well known, such a solution does not provide satisfactory results, since the filter required to decrease the noise sensitivity introduces detrimental time delays. As a result, model-based approaches would appear preferable.

A natural approach could consist in considering friction forces as negligible and proceed to observation of velocities [6], [10]). Unfortunately, neglected dynamics due to the assumption of perfect revolute joints require the use of robust techniques such as high-gain observers [4], which may generate a considerable level of the noise present in the reconstructed signals. As a result, smooth reconstruction of velocity must rely on a more exhaustive model accounting for friction forces. Such a point of view has already been exploited for example in [1] to estimate and control external forces for a manipulator robots, thanks to the error of an observer neglecting such forces. The integration of friction using a model is nevertheless a challenging problem since the contact properties are non-linear, difficult to calibrate and can moreover be variable due to external and not controllable conditions. Hence, it seems relevant to use adaptive control [3], [7] able to tackle this variability.

In this paper, a global observer coupling velocity and friction reconstruction is proposed. This double observation permits the on-line estimation of the friction reconstruction error and furthermore enables the adaptation of a contact model. As a result, unmeasured velocities in robot joints can be smoothly reconstructed thanks to friction estimation and adaptation. In Section II, the considered pendulum is briefly described as well as its modeling. Section III is devoted to the velocity and friction error observer design. This section presents in a first part the definition of a high-gain observer. The friction observer is then outlined and the proposed observer, which takes into account this preliminary friction estimation is described. Results relative to this new observer capabilities is then detailed in a next section. Section V is focused on the implementation of a simple adaptation law based on the friction estimation achieved. The adaptive law is described and experimental results are reported. Finally, Sections VI and VII summarize the results and briefly discuss ongoing and future work.

II. Methods and Experimental Platform

A. Inverted pendulum dynamics

The aim of this paper is the stabilization of an inverted rotational pendulum around its upward equilibrium position. The platform used for the development proposed was the Furuta pendulum depicted on Fig. 1. This device consisted of a controlled rotational arm, on which a free pendulum was mounted (Fig. 1). In this device, only the angle positions (denoted by ϕ for the arm and θ for the pendulum) were measured by encoders. As velocity measurement were required in the feedback control law for the control variable u—*i.e.*, the motor torque applied to the arm by an electrical motor—angular velocities ($\dot{\phi}$ and $\dot{\theta}$) had to be estimated.

B. Linearized dynamics

The model defining the evolution of Furuta Pendulum can be found in [12], [21], [23]. The stabilization application around the upward position (desired angles ($\theta_{Ref} = 0$, $\phi_{Ref} = 0$)) and considering that the control ensures limited errors

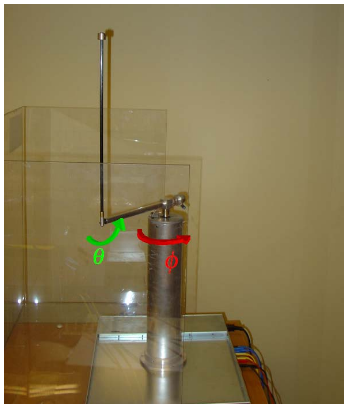

Fig. 1. Furuta pendulum, Dept. of Automatic Contol, Lund University

around this reference, the linearisation of the model can be achieved and leads to equation (1)

$$\begin{array}{rcl} \dot{x} & = & Ax + B_F\tau \\ y & = & Cx \end{array} \tag{1}$$

with the following notations

$$x = \begin{bmatrix} \theta \\ \phi \\ \dot{\theta} \\ \dot{\phi} \end{bmatrix}, \qquad A = \begin{bmatrix} 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \\ \alpha_1 & 0 & 0 & 0 \\ \alpha_2 & 0 & 0 & 0 \end{bmatrix}$$
$$C = \begin{bmatrix} I_2 & 0_{2\times 2} \end{bmatrix}, \quad B_F = \begin{bmatrix} 0 & 0 & \beta_4 & \beta_5 \\ 0 & 0 & \beta_3 & \beta_4 \end{bmatrix}^T \tag{2}$$

where α_i and $\beta_i, i \in 1..5$ are constant parameters defined by mechanical pendulum properties (length, mass and inertia), and τ is the torque in the arm joints, which comprises motor torque as well as friction torques:

$$\tau = \begin{bmatrix} F_\theta & u + F_\phi \end{bmatrix}^T \tag{3}$$

F_ϕ is the friction torque present in the "arm-joint" while F_θ is the friction in the "pendulum joint". If the model dedicated to the pendulum motion around upward position can be linearized, the non-linear friction behavior is preserved in the following of the paper.

III. Velocity and Friction Observer Design

A. High-gain (HG) observer

To the purpose of pendulum stabilization, design of state-feedback control law suggests the feedback of joint velocities. As confirmed by experiment, the computation of velocities by means of differentiation of measured angular position are not satisfactory. As a remedy, an observer approach using robot dynamic model can be implemented, sometimes neglecting the friction forces ($F_\phi = F_\theta = 0$). A velocity observer based on this assumption using this model must be based on robust techniques to compensate the neglected dynamics, such as high-gain observer used in [11]. This observer is here detailed by Eq. (4).

$$\dot{\hat{x}}_{HG} = A\hat{x}_{HG} + B_F \begin{bmatrix} 0 & u \end{bmatrix} + H(y - C\hat{x}_{HG}) \tag{4}$$

where u is the controlled torque applied on the arm joint and H the gain matrix, defined as follows:

$$H = \begin{bmatrix} \frac{\beta_1}{\varepsilon_1} & 0 & \frac{\beta_2}{\varepsilon_2^2} & 0 \\ 0 & \frac{\alpha_1}{\varepsilon_1} & 0 & \frac{\alpha_2}{\varepsilon_1^2} \end{bmatrix}^T \tag{5}$$

where ε_1 and ε_2 are positive constants while $\alpha_{1,2} > 0$ and $\beta_{1,2} > 0$ are chosen such that the real part of the roots of the polynomials

$$\begin{array}{l} s^2 + \alpha_1 s + \alpha_2 = 0 \\ s^2 + \beta_1 s + \beta_2 = 0 \end{array} \tag{6}$$

are negative.
A drawback with such techniques is the significant noise on observed velocities, resulting in a rough, contaminated control signal. To avoid this undesired effect of high-gain observers, an alternative velocity observer is proposed below.

B. Friction observer

Several models of friction can be found in the literature for various applications [8],[9], [5]. Whereas an elaborate description using the LuGre model [8] would be more complete, the simpler Dahl model was chosen to simplify the adaptation law defined in Sec. V-B.

$$\begin{array}{rcl} F & = & \sigma_0 z \\ \dot{z} & = & v - \frac{\sigma_0}{F_c}|v|z \end{array} \tag{7}$$

where z is an internal state of the Dahl model attached to a joint, v is the relative velocity in this joint, σ_0 and F_c being friction model parameters. The friction observer based on the Dahl model is defined by the equations

$$\begin{array}{rcl} \hat{F}_\phi & = & \sigma_0 \hat{z}_\phi \\ \dot{\hat{z}}_\phi & = & v_\phi - \frac{\sigma_0}{F_c}\left|v_\phi\right|\hat{z}_\phi + K_z(v_\phi) \end{array} \tag{8}$$

From the stabilization point of view, the friction is expected to be compensated by the controlled torque. As a result, only the friction torque of the arm joint (ϕ) was considered in the friction observer. The observer gain K_z can be designed in several ways, such as e.g., the following, proposed in [11]:

$$K_z = -\frac{\sigma_0}{\rho}\left(1 + \sigma_1\frac{\left|v_\phi\right|}{F_c}\right)\left[\varepsilon_\phi + \rho_2(\varepsilon_{v_\phi})\right] \tag{9}$$

where $\varepsilon_\phi = \phi - \phi^{Ref}$ is the difference between the actual position ϕ and the desired one ϕ^{Ref} in the arm joint, while $\varepsilon_{v_\phi} = v_\phi - v_\phi^{Ref}$ is the difference between the actual velocity and the desired one for the joint i; ρ and ρ_2 are design constants, tuning the performance of the observer of Eq. (8).

C. Velocity and friction error observer (VFE)

As friction estimation is available using the observer (8), it is possible to take part of this signal in a velocity observer. The integration of friction can be achieved via model (1). It can indeed be considered that the input torque τ is the addition of the controlled torque u (input of system) and the resisting torques F_ϕ and F_θ due to friction in the joint, respectively on the arm and on the pendulum, such as the definition (3). The new model with friction considered is then defined as following:

$$\begin{array}{rcl} \dot{x} & = & Ax+Bu+B_F F \\ y & = & Cx \end{array} \tag{10}$$

where B consists in the second column of the B_F matrix and $F=[F_\theta \quad F_\phi]^T$, constitutes a vector containing friction torques attached respectively to the arm and to the pendulum joints. In order to build the velocity and friction error observer, the model (10) derived from model (1) is used to propose the following observer:

$$\begin{array}{l} \dot{\hat{x}} = A\hat{x}+Bu+B_F(\hat{F}+\hat{\varepsilon}_F)+K_1(y-C\hat{x}) \\ \dot{\hat{\varepsilon}}_F = K_2(y-C\hat{x}) \end{array} \tag{11}$$

where $\hat{F}=[\hat{F}_\phi \quad 0]$ is defined by (8), while K_1 and K_2 are two gains tuned such that the matrix G defined by (12) is stable:

$$G = A_F - K_F C \tag{12}$$

with

$$A_F = \left[\begin{array}{cc} A & B_F \\ 0_{2\times4} & 0_{2\times2} \end{array}\right], \quad K_F = \left[\begin{array}{c} K_1 \\ K_2 \end{array}\right], \tag{13}$$

The observer error $\tilde{x}=x-\hat{x}$ obeys the dynamics

$$\dot{\tilde{x}} = (A-K_1C)\tilde{x}+B_F(\tilde{F}-\hat{\varepsilon}_F) \tag{14}$$

where $\tilde{F}=F-\hat{F}$ is the friction observation error using the observer (8).
If we consider that this friction estimation error $\tilde{F}$ is due to a poor estimation of parameters or a slow-varying parameter variation, this error can also be considered as slow-varying ($\dot{\tilde{F}}\approx 0$), since a parameter error affects mainly the convergence values of $\hat{F}$. This assumption is true for the Furuta pendulum except during sign modification of arm velocity ($\dot{\phi}$). These transients change very quickly and experimental tests show the global observer remain stable and effective. Thus, derivation of Eq. (14) leads to:

$$\ddot{\tilde{x}} = (A-K_1C)\dot{\tilde{x}}-B_F K_2 C\tilde{x} \tag{15}$$

According to the choice for observer gains K_1 and K_2, the observed error converges to zero. In view of equation (14), it results the convergence of the variable $\hat{\varepsilon}_F$ to the observed friction error $\tilde{F}$.

IV. Experimental Observer Results

A. Stabilization behavior

The control torque for pendulum stabilization was obtained using linear-quadratic control requiring access to the joint velocities [2]. The control signal resulting from such a law is denoted by u_{LQ}. In addition, a friction compensation module, which consists in the addition of friction observed via (8) can be computed. The stability of the whole control $u_{LQ}-F_\phi$ was demonstrated in [20].
The general behavior and control accuracy of pendulum stabilization is similar using VFE Observer or high-gain observer for velocity reconstruction. In order to verify this point, two tests of 20s were performed. In the first experiment, the control law was fed with the high-gain observer,

rad^2	With HG	With VFE
Mean ϕ^2	$3.5\cdot10^{-3}$	$2.3\cdot10^{-3}$
Std ϕ^2	$3.4\cdot10^{-3}$	$2.5\cdot10^{-3}$
Mean θ^2	$4.2\cdot10^{-5}$	$6.4\cdot10^{-5}$
Std θ^2	$4.7\cdot10^{-5}$	$7.7\cdot10^{-5}$

TABLE I
Properties of squared control error signals using HG and VFE, respectively.

while for the second, the VFE observer signals were used. Figure (2) shows in black dashed line the arm angle measured during the last ten second of both experiments for estimation using HG (*left*) and VFE (*right*), respectively.

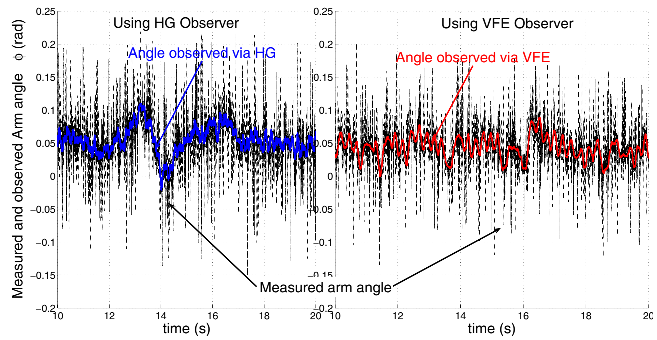

Fig. 2. Comparison of arm position observed via HG and VFE. The solid lines depict the estimated angle obtained with HG and VFE observer, respectively, while the dotted lines correspond to measured positions.

Table I shows the squared deviations of the arm and pendulum measured angles in both experiments, respectively. The mean value and standard deviation of these signals for both observers used are reported.

For the arm position(ϕ), we noticed that results were more accurate using VFE, while the pendulum angle (θ) was closer to zero using the high-gain observer. Nevertheless, these results relied on the parameters (σ_0 and F_c) entered into the friction observer. Several experiments showed that the velocity estimation using VFE observer were more robust with respect to calibration errors of the friction parameters due to time variation or poor off-line calibration. If the advantages of VFE observer does not appear clearly from a positioning accuracy point of view, the benefits of this approach lies mainly in the velocity reconstruction as well as in control signal results as pointed out hereafter.

B. Velocity reconstruction

The first objective of the observer proposed was to reconstruct the velocities in both of the joints with a reduced noise and without delay. Figure 3 shows the velocity reconstructed during the test based on VFE observer. During this test, both the observers were running simultaneously. The left part of the figure shows the arm velocity reconstructed using the high-gain observer ($\dot{\hat{\phi}}_{HG}$), while the right part depicts the arm velocity reconstructed via the VFE observer ($\dot{\hat{\phi}}$). On both part of the Fig. 3, the arm velocity reconstructed after

$(rad/s)^2$	HG ($\hat{x}_{HG}$)	VFE ($\hat{x}$)
Mean $(\dot{\hat{\phi}} - \dot{\phi})^2$	$31{\cdot}10^{-3}$	$9{\cdot}10^{-3}$
Std $(\dot{\hat{\phi}} - \dot{\phi})^2$	$48{\cdot}10^{-3}$	$13{\cdot}10^{-3}$
Mean $(\dot{\hat{\theta}} - \dot{\theta})^2$	$4.1{\cdot}10^{-3}$	$1.1{\cdot}10^{-3}$
Std $(\dot{\hat{\theta}} - \dot{\theta})^2$	$6.4{\cdot}10^{-3}$	$1.6{\cdot}10^{-3}$

TABLE II

COMPARISON OF SQUARED VELOCITY ERRORS BETWEEN HG AND VFE.

the test (called hereafter $\dot{\hat{\phi}}$ for arm and $\dot{\hat{\theta}}$ for the pendulum) obtained using a zero-phase Butterworth filter with a cut-off frequency of 5Hz is reported in blue dashed line [13].

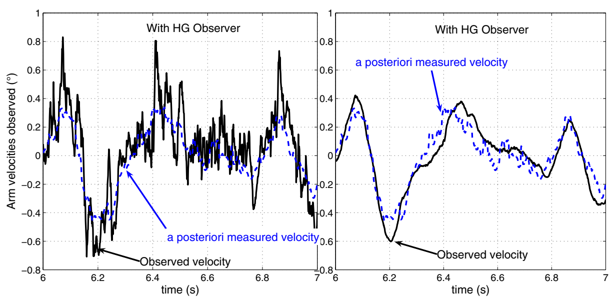

Fig. 3. Comparison of arm velocities observed via HG and VFE on the same experiment

Note that the arm velocity estimated by means of the VFE observer is less noisy, still without significant delay. The same fact can be observed on the pendulum velocity observed ($\dot{\hat{\theta}}$). Table II compares the properties of the square of the difference between observed velocities (using HG and VFE estimation) and the signal reconstructed *a posteriori*.

According to Table II, it can be noticed that the observation errors on velocities as well as noise contained in the signals were considerably reduced. Thanks to the on-line friction error estimation, the proposed observer was able to achieve a relevant velocity estimation with a low level of noise. As a consequence, these results allow to reduce the oscillations induced in the control law computation and consequently the hardness of the control signal sent to the actuator (torque applied to the arm joint). Figure 4 shows a comparison between control signals actuated when the control law was based on the high-gain observer (*left*), and when it was based on the VFE observer (*right*).

Note that the VFE observer indeed decreases the oscillations of control by means of reduction of noise in the velocities signal used for control law calculation. As it can be noticed thanks to Table I, this does not significantly change the general behavior of the controlled process, as the accuracy is not significantly modified. Nevertheless, it permitted reduction of noise-induced high-frequency variations in the actuator.

C. Convergence of $\hat{\varepsilon}_F$

The definition (11) of the proposed observer as well as the observer error dynamics (14) show that the intermediate vector $\hat{\varepsilon}_F$ used to ensure the convergence of velocity observer

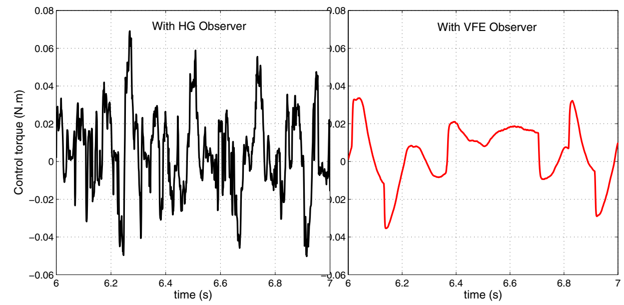

Fig. 4. Comparison of control signals using HG vs VFE Observers

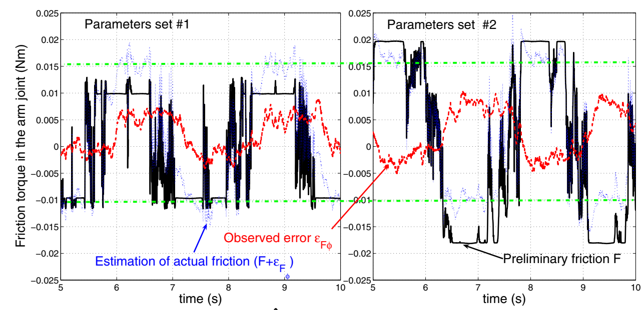

Fig. 5. Preliminary friction ($\hat{F}$) and friction friction error ($\varepsilon_{F\phi}$) observed

is supposed to reach the friction error vector $\tilde{F}$. As a result, an estimation $\hat{\varepsilon}_F$ of this error committed by the preliminary friction observer (8) is available. To check the relevance of this estimation, two trials without the friction compensation ($u = u_{LQ}$) were made. This leads to an oscillating behavior of the arm and pendulum around the references as friction is neglected in the control law calculation. The first trial was achieved with a set of parameters (set #1) in the Dahl model (8), which under-estimated the friction level, while the second was realized with another set of parameters (set #2) emphasizing the observed friction.

The results on friction observed $\hat{F}$ (depicted in black plain line) and its addition with error observed $\hat{F} + \hat{\varepsilon}_{F_\phi}$, which is expected to converge to the actual friction (depicted in blue dotted line) are shown in Fig. 5. The steady-state value recorded with a good estimation of Dahl model parameters is depicted on this figure in green dashed dotted line. Note that friction ($\hat{F}_\phi$) observation achieved via (8) was quite dependent from the parameters found by a calibration procedure. The friction estimates $\hat{F}_\phi$ were quite different for the two sets of parameters. For each of the sets, the error observed ($\hat{\varepsilon}_{F_\phi}$), depicted in red dashed line, converged to different values using the VFE observer. This modification in the friction error observed permitted the signal $\hat{F}_\phi + \hat{\varepsilon}_{F_\phi}$ (which is expected to converge to the actual friction) to have almost the same shape and to reach the same values of convergence whatever the set of parameters. As both trials were made in a very short time period, one can expect that the actual friction has not been affected by a modification of temperature nor humidity and let the friction conditions unchanged. The level of friction appears to be constant, close to the value reached by the signal $\hat{F}_\phi + \hat{\varepsilon}_{F_\phi}$, moreover very close to the level recorded with an accurate calibration. As a result, the observed error signal $\hat{\varepsilon}_F$ seems to be a relevant estimation of the error $\tilde{F}$ made using the preliminary friction observer and can then be used in order to allow adaptation of the Dahl model parameters with respect to variations in the experimental condition.

V. Friction parameter adaptation

The two parameters σ_0 and F_c required for the Dahl model computation need to be accurately estimated in order to obtain a precise compensation. This estimation was achieved off line using a preliminary calibration. Nevertheless, the conditions of adherence in the joints of a robot, denoted by these model parameters, were subject to change with respect to several factors. Even if this variation was slow, it affected the stabilization behavior and the stabilization control capabilities.

A. Parameter adaptation

For adaptation of the Dahl friction model, let us consider only one adaptive gain parameter able to modify the behavior of the whole friction model considered. To this purpose, a gain parameter K_σ was introduced in the friction observer (8) to grade the compensation of the estimated friction force $\hat{F}$. The new equations for the friction observer become:

$$\begin{array}{rcl} \hat{F}_\phi & = & K_\sigma \sigma_0 \hat{z}_\phi \\ \dot{\hat{z}}_\phi & = & v_\phi - \frac{\sigma_0}{F_c} \left| v_\phi \right| \hat{z}_\phi + K_z(v_\phi) \end{array} \quad (16)$$

K_σ is then a variable expected to modify the observed friction force $\hat{F}$ in order to reduce the observed error $\tilde{F}$, estimated by the variable $\hat{\varepsilon}_F$ defined in (11).

B. Adaptive algorithm

In this paper a simple adaptation law is considered, which shows the capability of using the error signal estimated $\hat{\varepsilon}_F$ to achieve a relevant modification of the friction model. A simple sensitivity-based gradient search algorithm was then used. The general expression for such an adaptation law is [3]:

$$\dot{K}_\sigma = -\gamma e \frac{\partial e}{\partial K_\sigma} \quad (17)$$

For the particular case considered, we have:

$$\dot{K}_\sigma = -\gamma \hat{\varepsilon}_F \sigma_0 \hat{z} \quad (18)$$

In friction compensation based on the Dahl model, the adaptive variable K_σ was initially set to 1. The aim of the adaptation law (18) was to permit the slow convergence of $\hat{\varepsilon}_F$ compared to the convergence of the observer.

C. Implementation

In practice, the parameters of friction model have to be different with respect to the sign of the joint velocity. The friction behavior is indeed different if the velocity in the considered joint is positive or negative. As a result, two different adaptive parameters K_σ^+ (when $\dot{\hat{\phi}} > 0$) and K_σ^- (when $\dot{\hat{\phi}} < 0$) were implemented in the algorithm to take into account these differences.

Moreover, the adaptation algorithms need to have sufficiently large excitations in order to permit a relevant convergence of the variable $\hat{\varepsilon}_F$. To allow a sufficient excitation, the velocity in the considered joint must be sufficiently large and the sign of this velocity must be preserved during some interval. To this purpose, a threshold on angular velocity was introduced. The adaptive algorithm was active when the velocity was above this bound. When the friction compensation is active in the control law, the stabilization is quite accurate and velocities are quite small and do not permit an efficient adaptation of parameter K_σ. As a consequence, the parameter K_σ was easier to adapt without active friction compensation (*i.e.*, when the total controlled torque u is equal to u_{LQ} without accounting for $\hat{F}$). The same control configuration as used in Sec. IV-C was then used for the results presented.

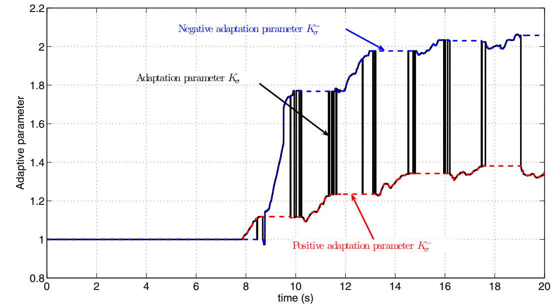

Fig. 6. Adaptive parameter K_σ recorded

D. Experimental results of adaptive observer

In order to show the effectiveness of adaptive algorithm, an experiment was made preliminary underestimated set of parameters. Initially, the adaptive parameter K_σ was set to 1. After the time t=7.8 seconds, the adaptive algorithm (18) was enabled and the parameter estimate could evolve. Figure 6 shows the evolution of K_σ in black solid line, while the red and blue dashed lines reported on this figure depicts the evolution of respectively K_σ^- and K_σ^+. Notice that each of these parameters converged slowly to almost constant values in the range $1.34 - 2.05$ which, in turn, provided an adapted friction estimation $\hat{F}$.

The friction estimated via the new friction observer (16) is depicted in black solid line in Fig. 7, the estimated error $\hat{\varepsilon}_F$ depicted in blue dotted line. Notice that after 7.8 s, the steady-state values of friction torque observed in the arm joint were modified and converged to values around 0.018 Nm when the joint velocity was negative and around -0.012 Nm for $\dot{\phi} > 0$. These values were similar to the ones obtained with an accurate calibration of the Dahl model parameters achieved before this experiment (*red dash-dotted line*).

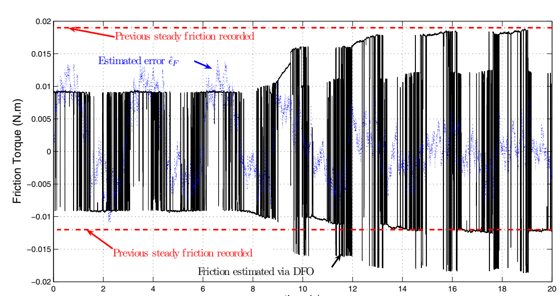

Fig. 7. Adapted friction observed $\hat{F}$ and error estimated $\hat{\varepsilon}_F$

This result demonstrates design features of an adaptive friction observer based on the velocity and friction error observer proposed in Sec. III-C. Nevertheless, the use of a friction compensation module, decreasing considerably the range of oscillations observed, does not permit sufficient excitation of joint velocity and the adaptation is inactive when velocity is not sufficiently large. From an application point of view, a procedure for the automatic update of friction parameters must be made when the accuracy expected is not reached.

VI. Discussion

There exist several previous approaches to model-based observers for mechanical systems with friction [19], [14], [16], [24], [15], [22], [20], [17], some of which include proofs of stability. In this paper, the nested structure of the two observers and the adaptation complicates stability analysis which is still incomplete.

Future research is to be focused on the design of a more complete adaptive algorithm able to adapt more parameters. Whereas other friction model were already used with such an observer for various friction models the LuGre model [17], [11], the adaptive law proposed was applied to the Dahl model [9]. The extension to adaptive schemes for more complete models is under study. Finally, the algorithm is also planned to be experimentally tested on all of the joints of the Furuta pendulum (as reported here, the friction observer was implemented only for arm angle friction) and to be applied to the control dedicated to periodic motion and on other experimental devices.

VII. Conclusions

This paper proposes an observer dedicated to joint velocities estimation taking friction into account. It permits relevant estimation for control with respect to the accuracy of the estimation as well as the quality of signal (reduction of noise compared to classical friction observation loops). It provides a smooth control signal to the actuator, preserving the mechanism from high-frequency variation and reducing the potential oscillations due to noisy signals generated in classical velocity reconstruction methods. Moreover, it integrates a model of friction (which can be used for friction compensation algorithm) and estimate in the same time the error generated by poor parameter identification.

As a result, it makes possible the use of the error signal in the control loop in order to correct the friction observed via a model-based technique. In this paper, such a friction observation error was exploited to design an adaptation algorithm able to update friction model parameters. The adaptation law proposed is very simple, but permits to show the feasibility of parameters adaptation limited for the moment to a unique adapted parameter.

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