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Robust Handwriting Estimator from Two Forearm Muscles Activities

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Abstract

This paper aims to reconstruct handwriting letters only from two forearm ElectroMyoGraphy signals (EMG) activity. Previously, handwriting parametric models have been proposed for this purpose with some success. However these models presents a very high parameters variation due to the problem of EMG variability and its unpredictable propriety. To improve reconstruction accuracy, we developed interval observer, which allows to fuse two Luenberger observers, the first was implemented for upper parameters and the second for lower ones. The proposed method acting as a true handwriting predictor, has shown improvement over the previously proposed techniques, it can be applied with high variability of results across subjects. Moreover, handwriting interval observer model is robust and appropriate for different applications, as: myoelectric prostheses, clinical rehabilitation or even military applications, etc.

Keywords: Handwriting letters, EMG, interval observer; Luenberger observers, parameters variation, robust.

I. INTRODUCTION

Handwriting is considered as an important means of communication and an unavoidable ability for academic, professional and social integration. It contains information that can characterize a person to express his/ her social, academic level, intellectual component, and even the psyco-physical personality of the writer, etc.), [1-2].

Unlike characterization of elementary hand movements (opening, closing, etc.), generally developed by myoelectric prostheses, handwriting has inspired little researchers to propose models characterizing this biological process. In this context, Mc-Donald proposed an electronic version of a physical model proposed by Van Der Gon, [3-4]. Yasuhara proposed non-linear differential equations to describe the handwriting motion using two equivalent muscles forces exerted to the pen moving in the plane, [5].

Other researches, used the relationship between the muscles activities and the hand movement has inspired many researches to model the writing motion.

In a first analysis, Sano proposed a differential model of second order to reproduce different patterns (Arabic letters and geometric forms) written by many people, [6]. This study focuses on recording the activities of the forearm muscles, named ElectroMyoGraphy signals (EMG), considered as inputs of the developed model. In 2009, Linderman, developed a parametric model based on Wiener filter to reconstruct symbols from 0 to 9, using 8 bipolar surface electrodes placed on the hand and the forearm muscles, [7]. In order to ameliorate the handwriting modeling, Okorokova presented a dynamical model to improve reconstruction of manuscript from multichannel electromyographic recordings, [8]. A multimodel approach was proposed by Chihi to characterize of the handwriting process, [9].

In summary, handwriting physical models based, allowing to mimic this biological motion show limited results. In fact, it's very difficult to find mathematical model which can represent all the complexities of the handwriting process. Likewise, measurement models, based on inputs/outputs data mapping do not also show satisfactory results.

The unpredictable characteristics and the variation of the models' parameters explain the lack of precision of the previous results. Indeed, the complexity of the handwriting system is essentially related to the variability of muscles activities and writing, which interferes with physical and psychical variation of scripters that should be taken in account for the process of modeling. Further, Electromyography signals may be considered as unpredictable, i.e. the same person can have different EMG signals even to reproduce the same pattern, [10-11].

These constrains make the process hard to be exactly modeled, which involves model uncertainty.

Starting from this problematic, the present paper deals with an interval observer approach to model the handwriting movement in the plane. In fact, this type of observer is deduced from two Luenberger observers, upper and lower, securing the parameter variations, in order to design an interval observer of preference, [12-16].

Unlike, the most of the handwriting models, the advantage of our approach is to use only two forearm muscles activities and to characterize complex pattern, especially cursive Arabic letters, which are composed by combined movements, vertical, horizontal, oblique, etc. Besides, this study aims to aims to ameliorate all parametric models which requires an adjustment of the parameters value. Moreover, this approach, is appropriate for many rapidly expanding fields and practices, including biomedical engineering, robotics and biofeedback therapy or even military applications.

This article is organized as follows: In section 2, we present the problem statement to show the limitations of some previous handwriting models. Section 3 develops the proposed model based on interval observer. Simulation results and interpretations of the response of the proposed approach are presented in section 4. Finally, the conclusion and perspective of this work are presented.

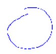
II. PROBLEM STATEMENT AND PRELIMINARIES

In order to model the handwriting process, Sano proposed in [6] an experimental approach allowing to record at the same time the coordinates of some graphical traces, see table1, in the plane (*x,y*) and ElectroMyoGraphy signals of two forearm muscles, called EMG signals, intervening the production of the writing act the first is responsible of horizontal movement and the second of vertical movement. The obtained signal must be sampled and then converted into discrete values in order to be stored in digital form.

Materials used in the experimental approaches is as flows:

- digital table of the brand "WACOM, KT-0405-RN"
- surface electrodes
- data logger, of the "TEAC, AR-C2EMG1" type
- computer.

TABLE 1. Considered Arabic letters and geometric forms

Description of shape	Shape
Line left to right and then back to starting point	
Line from right to left and back to starting point	
Line from top to bottom then return to the starting point	
Line from bottom to top and back to the starting point	
Circle in a clockwise motion	
Circle in a movement to the left	
Closed triangle in a clockwise motion	
Closed triangle in a movement to the left	
Arabic letter "HA"	
Arabic letter "SIN"	
Arabic letter "AYN"	

Based on the real data measurements, recorded from this experimental approach, Sano proposed a parametric model expressed as follows:

$$\begin{cases} \dfrac{dx(t)}{dt} = \sum_{m=1}^{3} a_x(m) E_1(k-m-N_1) + \\ \qquad \sum_{m=1}^{3} b_x(m) E_2(k-m-N_2) \\ \dfrac{dy(t)}{dt} = \sum_{m=1}^{3} a_y(m) E_1(k-m-N_1) + \\ \qquad \sum_{m=1}^{3} b_y(m) E_2(k-m-N_2) \end{cases} \quad (1)$$

where notation means as follows:

t	: continuous time,
a_x, a_y, b_x, b_y	: weighting coefficients,
k	: discrete time,
m	: discrete delay time,
N1, N1	: discrete dead time,
E1,E2	: input signals.

We note that, parameters of model (1) are not the same for the different written patterns.

Figure 1 shows the difference between the real and the estimated Arabic letter, SIN. This figure shows the result of applying the data of a letter with the parameters of another representing the same type of letter. The solid line shows experimental data and the dotted line denotes the model response. This figure shows the limits of this model as well as the interest of developing adaptable parameters according to the change of data.

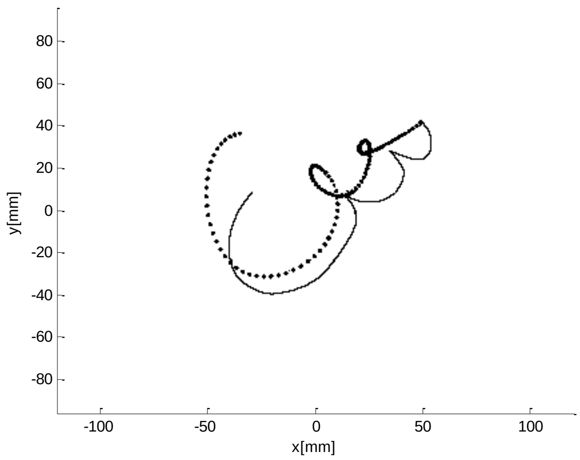


FIGURE 1. Predicted Arabic letter "SIN" by Sano model

Based on the experimental approach previously presented, another mathematical model was developed to characterize the handwriting motion from two muscles activities of the forearm recorded during the writing process, [17]. This approach allows reproducing Arabic letters and some geometric forms.

The Proposed model is given by the following equations:

$$\begin{aligned} x_e(k) &= \sum_{i=1}^{4} \hat{a}_{ix}\, y_e(k-i) + \sum_{i=1}^{4} \hat{b}_{ix}\, x_e(k-i) \\ &\quad + \sum_{i=1}^{5} \hat{c}_{ix}\, e_1(k-i+1) + \sum_{i=1}^{5} \hat{d}_{ix}\, e_2(k-i+1) \\ y_e(k) &= \sum_{i=1}^{4} \hat{a}_{iy}\, x_e(k-i) + \sum_{i=1}^{4} \hat{b}_{iy}\, y_e(k-i) \\ &\quad + \sum_{i=1}^{5} \hat{c}_{iy}\, e_1(k-i+1) + \sum_{i=1}^{5} \hat{d}_{iy}\, e_2(k-i+1) \end{aligned} \tag{2}$$

with:

x_e and y_e : Estimated model outputs vector, relative to pen-tip position according to x and y movements respectively

e_1, e_2 : Electromyography signals

$a_{ix}, b_{ix}, c_{ix}, d_{ix}$: Parameters relative to the model output x_e according to x movement

$a_{iy}, b_{iy}, c_{iy}, d_{iy}$: Parameters relative to the model output y_e according to y movement

Parameters of the proposed model are estimated by exploiting the recursive least squares algorithm.

Figure 2 presents some examples of Chihi handwriting model. Produced with applying parameters of a specific letter with the data of another letter of the same type. The dotted line shows experimental data and the solid line denotes the model response.

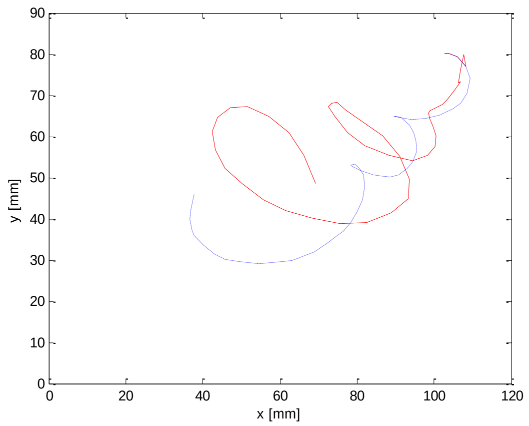


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FIGURE 2. Chihi handwriting model responses

For Both models, (1) and (2), it's important to note that, the models structure is fixed whatever the letter generated, however, parameters vary according to the changes of the inputs/outputs, which requires a continuous readjustment of the parameters.

This limitations lead us to ask the following questions:

How can we characterize several graphic traces without reestimating the model's parameters?

How can we propose a model where the parameters can be adapted according to the data change?

III INTERVAL OBSERVER FOR HANDWRITING MODELING

Interval observer should provide good solutions for systems with large uncertainties. This kind of observer is in fact the association of two observers, one observe the lower bound of the states and another observe the upper bound of the system. These observers are stable and they converge if the entries are persistent and bounded. They are robust to unknown inputs, and the speed of convergence is partially adjustable, they have been developed in [12-16].

In this study, we used Chihi model to validate the proposed approach. Figure 2 presents the principle of the proposed handwriting model approach based on interval observer.

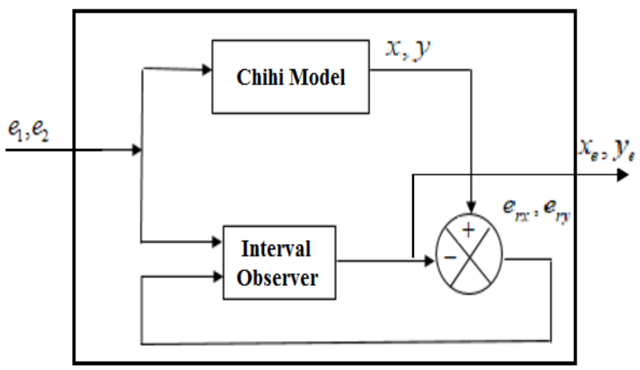


FIGURE 3. Proposed handwriting model based on interval observer

The representation state of the model (1) is provided by the following system of equations:

$$\begin{cases} X(k) = A\,X(k-1) + B\,U(k) \\ Y(k) = C\,X(k) \end{cases} \tag{3}$$

with:

X : state vector containing estimated coordinates x_e and y_e,

Y : output vector contains the estimated coordinates of produced graphic traces x_e and y_e at the instant k,

U : Input vector containing the two electromyograpy signals (e_1 , e_2).

The state matrix A, contains the model parameters $a_{ix}, b_{ix}, a_{iy}, b_{iy}$ relative to the model delayed outputs x_e and y_e. B is the input matrix containing the parameters $c_{ix}, d_{ix}, c_{iy}, d_{iy}$ associated to the inputs signals, and *C* is the output matrix.

Below the characteristic equation of Luenberger observer:

$$\begin{cases} \hat{X}(k) = A\hat{X}(k-1) + BU(k) + K(Y(k) - \hat{Y}(k)) \\ \hat{Y}(k) = C\hat{X}(k) \end{cases} \quad (4)$$

with:

$\hat{X}$: Estimated state vector, in our study it contains the delayed estimated outputs, relative to x and y movements, on the instant *k-1*, *k-2*, *k-3* and *k-4*,

$\hat{Y}$: Output vector, contains the estimated coordinates at the current instant *k*.

$Y - \hat{Y}$: The error vector,

K: The observer gain.

e_{rx} and e_{ry} are the difference between the process outputs and the observer estimated outputs, according to x and y axis respectively, is expressed as follows:

$$\begin{cases} e_{rx}(k) = x(k) - x_e(k) \\ e_{ry}(k) = y(k) - y_e(k) \end{cases} \quad (5)$$

Indeed, for each kind of letter, we define two parameters' ranges, upper and down. When a parameter does not belong to one of these intervals, the proposed approach allows to adjust this value to ameliorate the result of the estimated pattern.

- ✓ **superior: superior observer**

$$\begin{cases} \bar{\hat{x}}(k) = A\bar{\hat{x}}(k-1) + BU(k) + k(\bar{y}(k) - \bar{\hat{y}}(k)) \\ \bar{\hat{y}}(k) = c\bar{\hat{x}}(k) \end{cases} \quad (6)$$

- ✓ **Lower: lower observer**

$$\begin{cases} \underline{\hat{x}}(k) = A\underline{\hat{x}}(k-1) + BU(k) + k(\underline{y}(k) - \underline{\hat{y}}(k)) \\ \underline{\hat{y}}(k) = c\underline{\hat{x}}(k) \end{cases} \quad (7)$$

The coordinates of the estimated shape are calculated as follows:

$$\begin{cases} x_e = \alpha\underline{\hat{x}}(k) + \beta\bar{\hat{x}}(k) \\ y_e = \alpha\underline{\hat{y}}(k) + \beta\bar{\hat{y}}(k) \end{cases} \quad (8)$$

with:

$\alpha \in [0,1]$

$\beta \in [0,1]$, $\alpha + \beta = 1$

III. RESULTS AND DISCUSSION

In this section, we will compare the responses of different models elaborated by the proposed approach, for two types of graphic traces, namely the Arabic letter "HA" and the Arabic letter "SIN". These traces are considered as complex shapes that contain abrupt changes of trajectories.

In this study, we considered two writers, writer 1 and writer 2, each one produces a letter, HA or SIN, many times. This allows to define upper and lower intervals for each kind of letter.

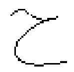
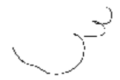
To valid this approach, we apply, inputs/outputs data for a considered model, which, we don't know its parameters. Table 3 presents the comparison of the validation result between the proposed approach and the parametric model described in (2).

During the experimental approach presented in section 2, each writer wrote each type of letter 3 times. Thereby, we develop a definite model for each letter.

In order to validate the interval observer approach proposed, table 2 presents the ranges of parameters for each kind of letter ("HA" and "SIN") written by two writers (writer 1 and writer 2). These parameters are computed based on Chihi handwriting model. According table 2, parameters' intervals are different from a writer to another and even between the different kind of letters generated by the same writer. Table 2 clearly shows very high parameters' interval difference, which indicates that handwriting is very person-specific. After analyzing the different parameters, we define two observers, upper and lower. The combination of these observers is according the mathematical relations (6) to (8).

Table 2 allows to visually compare the estimation of letters obtained with the two methods (Chihi model and interval observer model). As we can see from these figures, the proposed approach furnishes good writing reconstruction, natural and ergonomically plausible, than that based exclusively on the measurements. Besides, results show a significant improvement previously reported by Chihi handwriting model.

TABLE 2. Parameters' intervals of Chihi handwriting model

Parameters' interval	**Arabic letter "HA"** 			**Arabic letter "SIN"** 		
	Writer 1	**Writer 2**	**Writer 3**	**Writer 1**	**Writer 2**	**Writer 3**
ax	[-0,2 0,4]	[-0.8 0.8]	[-1 2]	[-2.5 0.5]	[-0.3 3]	[-0.7 0.4]
bx	[-0.7 0]	[-1.2 0.8]	[-1,8 1 ,8]	[-1.5 .5]	[-0.8 0.5]	[-1.5 0.5]
cx	[-30 19]	[-20 18]	[-198 300]	[-2 3]	[-18 20]	[-7 0.4]
dx	[-5 8]	[-2 3,5]	[-5 8]	[-1.2 1]	[-3 5]	[-0.4 0.4]
ay	[-0,5 0,5]	[-0,5 0,5]	[-2 1,8]	[-0.2 1]	[-1 1]	[-0.2 0.9]
by	[-1 0,4]	[-1 0.8]	[-1.8 2.1]	[-0.8 0]	[-1 0.3]	[-1.5 0.5]
cy	[-18 20]	[-18 10]	[-198 300]	[-3 2]	[-0.8 0.8]	[-8 10]
dy	[-19 19]	[-5 5]	[-100 50]	[-3 2]	[-13 10]	[-3.5 3.5]

Indeed, interval observer allows reconstruction of handwriting letters even when parameters were not estimated directly by model (1). Otherwise, handwriting interval observer approach can be considered as a robust method allowing to reconstruct scripts even if we use data from which the model has not been established.

This method has shown improvement over the previously proposed techniques, it can be applied with high variability of results across subjects.

After analyzing the different parameters, we define two observers, upper and lower. The combination of these observers is according the mathematical relations (6) to (8).

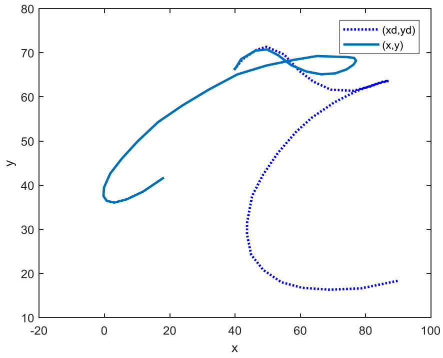
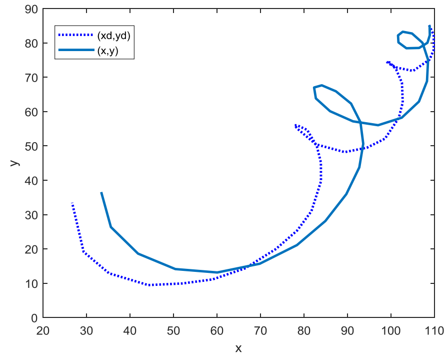
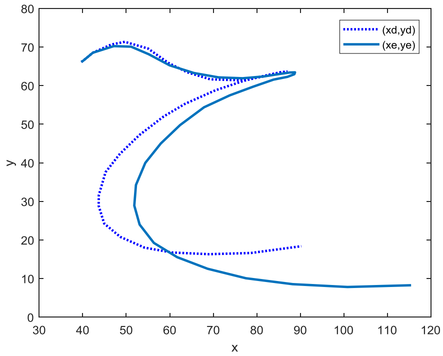
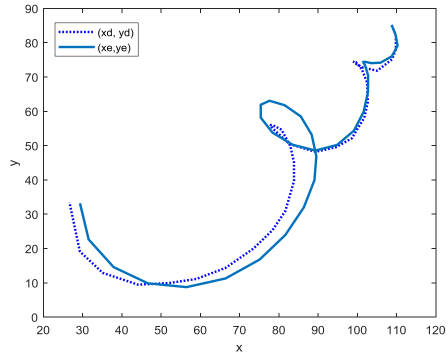
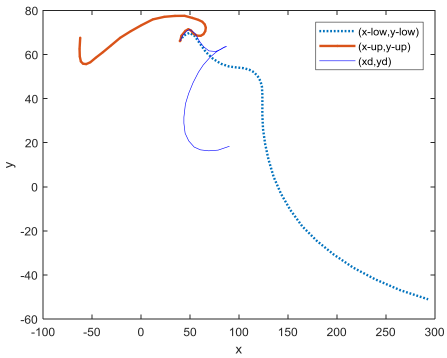
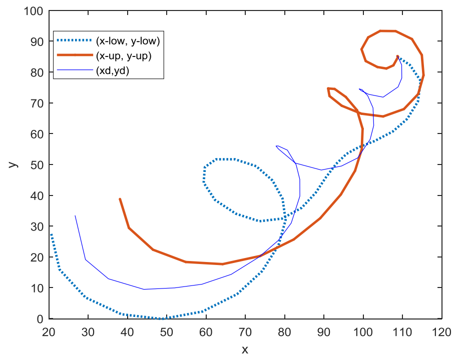
Table 2 allows to visually compare the estimation of letters obtained with the two methods (Chihi model and interval observer model).

We note that (*xd,yd*) are the desired letter's coordinates, (*x,y*) Chihi model response, (*xe,ye*) response of interval observer model, (*x-low, y-low*) response of the lower observer and (*x-up, y-up*) response of upper observer.

As we can see from these figures, the proposed approach furnishes good writing reconstruction, natural and ergonomically plausible, than that based exclusively on the measurements. Besides, results show a significant improvement previously reported by Chihi (model (1) and Sano (model (2)) handwriting models.

Indeed, interval observer allows reconstruction of handwriting letters even when parameters were not estimated directly by model (1). Otherwise, handwriting interval observer approach can be considered as a robust method allowing to reconstruct scripts even if we use data from which the model has not been established.

TABLE 3. Simulation results of the proposed handwriting interval observer

	Writer 1	Writer 2
Model (2)		
Interval observer based model		
		

This method has shown improvement over the previously proposed techniques, it can be applied with high variability of results across subjects.

IV. CONCLUSION AND FUTURE WORK.

In this paper we investigated the relationship between handwriting Arabic letters and two forearm EMG signals. We optimized handwriting parametric models in order to reconstruct the pen coordinates moving in the plane. The proposed approach is based on the interval observer, constituted by two observers, upper and lower, fixing the upper and lower variations of models' parameters.

We showed that this method is considered as robust and significantly outperforms previously proposed approaches in previous works. Besides, it allows to overcome the problem of parameters learning. The proposed approach can be considered as an alternative solution for the modeling of Linear Variable Parameters systems.

REFERENCES

[1] Meulenbroek R.G.J, Thomassen AJ.W.M, 1991, "Stroke-direction preferences in drawing and handwriting", Human Movement Science, Vol. 10, pp. 247-270.

[2] Viviani P., Terzuolo C.A., 1983, "The organization of movement in handwriting and typing". Lang Prod Vol. 2, pp. 103–146.

[3] Bitzer S. and Van der Smagt P., 2006,"Learning EMG control of a robotic hand: towards active prostheses," Proceedings IEEE International Conference on Robotics and Automation, Orlando, FL, pp. 2819-2823.

[4] Schulz S., Pylatiuk C., Reischl M., Martin J., Mikut R., and Bretthauer G., 2005, “A hydraulically driven multifunctional prosthetic hand,” Robotica, 23 (3), pp. 293–299.

[5] Zecca M., Micera S., Carrozza M. C. and Dario P., 2002, "Control of multifunctional prosthetic hands by processing the electromyographic signal". Crit Rev Biomed Eng Vol. 30, pp. 459-485.

[6] Scott R. N., Parker P. A., 1988, "Myoelectric prostheses: state of the art", J Med Eng Technol, Vol. 12, pp. 143-151.

[7] Jerard R. B., Williams T. W. and Ohlenbusch C. W., 1974, "Practical Design of an EMG Controlled Above Elbow Prosthesis", Conference on Engineering of Devices for Rehabilitation, Tufts Univ. School of Med., p. 73.

[8] Jacobson S. C., Knutti D. F., Johnson R. T. and Sears H. H., 1982, "Development of the Utah Artificial Arm," in IEEE Transactions on Biomedical Engineering, vol. BME-29, No. 4, pp. 249-269.

[9] Artemiadis P. K. and Kyriakopoulos K. J., 2010, "An EMG-Based Robot Control Scheme Robust to Time-Varying EMG Signal Features," in IEEE Transactions on Information Technology in Biomedicine, 4(3), pp. 582-588.

[10] MacDonald J.S., 1964, "Experimental studies of handwriting signals", Mass. Inst. Tech. PhD Dissertation, Cambridge.

[11] Van Der Gon D., Thuring J.P., Strackee J., 1962, "A handwriting simulator", Physics in Medical Biology, pp. 407-414.

[12] Yasuhara M., 1975, "Experimental studies of handwriting process", Rep. Univ. Electro-Comm., 25 (2), pp. 233-254.

[13] Sano M., Kosaku T. and Murata Y., 2003, "Modeling of human handwriting motion by electromyographic signals on forearm muscles", CCCT’03, Orlando-Florida.

[14] Linderman M., Lebedev M. A., and Erlichman J. S., 2009 "Recognition of handwriting from electromyography", PLoSONE, 4 (8), pp. 679.

[15] Okorokova E., Lebedev M., Linderman M. and Ossadtchi A., 2015, "A dynamical model improves reconstruction of handwriting from multichannel electromyographic recordings". Front. Neurosci, Vol. 9, pp.389.

[16] Chihi I., Abdelkrim A., Benrejeb M., 2016, "Multi-model approach to characterize human handwriting motion", Biol Cybern, Springer, 110 (1), pp. 17–30.

[17] Scheme E., Fougner A., Stavdahl O., Chan A., and Englehart K., 2010, "Examining the adverse effects of limb position on pattern recognition based myoelectric control", in Proc. 32nd Annu. Int. Conf. IEEE Eng. Med. Biol. Soc., Buenos Aires, Argentina, pp. 6337–6340.

[18] Kamavuako E. N., Rosenvang J. C., Bøg M. F., Smidstrup A., Erkocevic E., Niemeier M. J., Jensen W., and Farina D., 2013, "Influence of the feature space on the estimation of hand grasping force from intramuscular EMG", Biomed. Signal Process. Control, 8, (1), pp. 1–5.

[19] Dinh T.N., Mazenc F., Niculescu S. I., 2014, "Interval observer composed of observers for nonlinear systems, 13th European Control Conference", pp.660–665.

[20] Cacace F., Germani A., and Manes C., 2015, "A New Approach to Design Interval Observers for Linear Systems", IEEE Trans. Autom. Control, 60 (6), pp. 1665-1669.

[21] Ito, H., and Dinh, T. N., 2018 "Interval Observers for Global Feedback Control of Non linear Systems with Robustness with respect to Disturbances", European Journal of Control, Vol. 39, pp. 68-77.

[22] Degue, K. H., EÞmov, D. and Richard, J. P., 2018 "Stabilization of Linear Impulsive Systems under Dwell-Time Constraints: Interval Observer-Based Framework", European Journal of Control, Vol. 32, pp. 1-14.

[23] Chihi, I., Abdelkrim, A. et Benrejeb, M., 2011, "Parametric identification of handwriting system based on RLS algorithm", IEEE International Conference on Control, Automation, and Systems, (ICCAS), Seoul.