9th International Workshop on Innovative Simulation for Healthcare
17th International Multidisciplinary Modeling & Simulation Multiconference

ISSN 2724-0371 ISBN 978-88-85741-50-8 © 2020 The Authors.
DOI: 10.46354/i3m.2020.iwish.007

Handwriting prototype based on FPGA hardware implementation

Ichrak Jeridi[1], Ines Chihi[1,*], Lilia Sidhom[1], and Ernest Nlandu Kamavuako[2]

[1]Laboratory of energy applications and renewable energy efficiency, University of Tunis El Manar, Tunisia
[2]Centre for Robotics Research, Department of Engineering, Faculty of Natural and Mathematical Sciences, King's College London

[*]Corresponding author.ines.chihi@enib.rnu.tn

Abstract

Handwriting is an important means of communication that can characterize a person and express his academic level, intellectual component, and even the psycho-physical personality of the writer, the temperamental tendencies, and even psychic state. Writing is expressed through motions of the upper limbs and with the availability of different muscle activities, named ElectroMyoGraphy signals (EMG). Forearm EMG driven models can allow reconstruction of individual handwriting. By recovering the coordinates of some shapes generated by a mathematical model allowing the prediction of handwriting on the plane (x, y) from EMG signals, this paper deals with handwriting prototype using hardware implementation based on Field Programmable Gate Arrays (FPGA) of the bi-axis control algorithm to generate human handwriting manuscript in the plan. The presented bi-axis control law is designed in the Xilinx System Generator environment let generate handwriting shapes and complex cursive letters. Comparative analysis between the hardware implementation results generated by the proposed prototype and the recorded data is then presented to show good concordance between the real and the reconstructed data.

Keywords: Handwriting prototype, FPGA, bi-axis control algorithm, human handwriting, Xilinx System Generator

1. Introduction

The development of bioelectric interfaces is considered as an important research field and health concern. In addition to clinical applications, bioelectric interfaces can be used in robotics applications or biofeedback therapy or even to mimic some human actions (walking, gripping objects, etc), (Scheme et al, 2010) and (Kamavuako et al, 2013).

Handwriting motion is considered a complex human motion and a communication tool, indispensable for social, cultural, and scholar integration. The execution of handwriting movements requires complex coordination between different biological processes including the central and peripheral nervous systems with high coordination of muscles (Chihi et al, 2012,2017). In the literature, several handwriting studies are related largely to kinematic handwriting analysis, writing recognition, or medical diagnostics (e.g. Parkinson, Alzheimer, etc) (Plamondon et al, 1993) and (Fischer and Plamondon,2017). Several other investigations are proposed to control artificial hand from muscle activities (Electromyography, EMG), limited to perform elementary movements (opening, closing, etc.) targeting the amputee population (Zecca et al, 2002) and (Bitzer and Van Der Smagt, 2006). For example, a learning EMG device to move four fingers was proposed in (Bitzer and Van Der Smagt, 2006). Schulz et al. proposed a hydraulically driven multifunction prosthesis hand (Schulz et al, 2005). Other artificial hands controlled by EMG activities were presented in (Zecca et al, 2002), (Schulz et al,

© 2020 The Authors. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY-NC-ND) license (https://creativecommons.org/licenses/by-nc-nd/4.0/).

2005), (Jerad et al, 1974) and (Sano et al, 2003).

Despite the long use of EMG signals in hand motion recognition, the characterization of handwriting from the EMG signals of the upper limb has received limited attention. Indeed, the complexity of this process and the intricate relationship between writing and muscle activities makes it difficult to be well modeled and inserted in bioelectric devices. Nevertheless, studies have shown that handwriting motion in the XY-plane can be modeled only from forearm muscle activities. In a first analysis, Sano et al.developed an experimental approach allowing the recording of cursive writing (letters and geometric forms) and the related EMG signals of two forearm muscles (Sano et al, 2003). From this database, a non-linear model was developed to estimate handwriting traces only from EMG signals (Chihi et al, 2015). Using the same experimental basis, several compartmental models have been proposed to improve Sano's approach (Chihi and Benrejeb, 2018) and (Chihi et al, 2018). In 2009, Linderman et al. defined a classification device of manuscript symbols from 0 to 9 based on four EMG signals of the forearm and the hand (Linderman et al, 2009). Improvements in this model have also been proposed in (Okorokova et al, 2015). Another handwriting model from muscle activities was developed by Li et al (Li et al, 2013) Based on these studies, we can consider the hand as a bi-axis control device, represented by two stepper-motors that assures horizontal and vertical movements respectively. The combination of these movements enables the displacement of a pen in the XY-plane.

As an extension of the work presented in (Chihi et al, 2015), the present paper deals with hardware/software implementation of the Bresenham controller on Field-Programmable Gate Array (FPGA) to produce script traces. We also develop a handwriting prototype allowing us to mimic Arabic letters and geometric shapes in the XY-plane, written at high speed. This makes the proposed approach very suitable for FPGA devices, which is characterized by its great flexibility and parallel processing. Furthermore, with FPGA devices, it is possible to adapt the design of a robotic system to achieve the requirements of the application and manage complex tasks in real-time [19]. Therefore, FPGA has been increasingly exploited in multi-axis control systems.

In (Shilpa and Shriramwar, 2009) and (Martinez-Prado et al, 2013), based on the FPGA device, the implementation of multiple-axis motion controllers was proposed. These controllers performed good control performances, compact implementation, modules reusability, and a low cost. Based only on two axis X and Y, this work presents an implementation of the Bi-axis controller on the FPGA device, to generate cursive handwriting and taking into account the personal properties of the writer. This paper is organized as follows: The first section focuses on the presentation of the handwriting experimental approach and the studied system description. In the second section, we propose new hardware architecture to generate some handwriting shapes. The third section shows the implementation of the proposed solution on the FPGA card. Simulation results and experimental results are finally given.

2. Materials and Procedures

As shown in (Chihi et al, 2015) and (Chihi et al, 2018), handwriting movement in the XY-plane, can be presented by two EMG signals (EMG1 and EMG2) of the most active forearm muscles, namely the "Abductor Pollicis Longus" and the "Extensor Capri Ulnaris, which are responsible for the vertical and horizontal displacement respectively. To characterize handwriting movements, an experimental approach was proposed, in Hiroshima City University, to record at the same instant cursive Arabic letters or geometric forms and two forearm EMG signals (Sano et al, 2003). The measured data were synchronized by sending a step signal from the parallel interface port on the computer to the data recorder. This experimentation did require the following equipment: a Digital table of the brand "WACOM, KT-0405-RN", Pre-amplifiers "TEAC, AR-C2EMG1", a Data recorder "TEAC, DR-C2", Bipolar surface electrodes (MEDICOTEST, Blue Sensor N-00-S) and a Computer.

Figure. 1 depicts the positions of the electrodes on the writer's arm. Electrodes, indicated by "ch1 ", is relative to the first muscle (".Abductor Pollicis Longus" and those relative to the second muscle ("Extensor Capri Ulnaris"x) are indicated by "ch2". The trace of the Arabic letter, ح, "HA", written by one participant is shown in Figure 2 together with the produced EMG signals and single-axis traces. Due to the stochastic nature of the EMG signals, a variety of signal processing techniques are used to make EMG waveforms easier to interpret.

Indeed, the fluctuation of EMG‘s magnitudes can be filtered to obtain new curves -called Integrated EMG (IEMG), represented by dotted red curves in Figure 2 (b). We note IEMG1 and IEMG2, the Integrated EMG1, and Integrated EMG2 signals, respectively. The experimental approach is mainly based on bioelectrical signals of two muscles, considered as biological actuators.

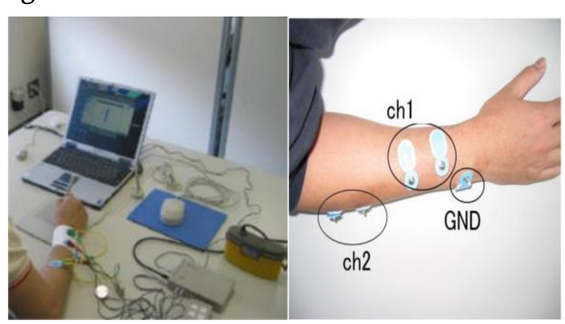

Figure 1. Experimental assembly and electrodes' positions on the writer's arm

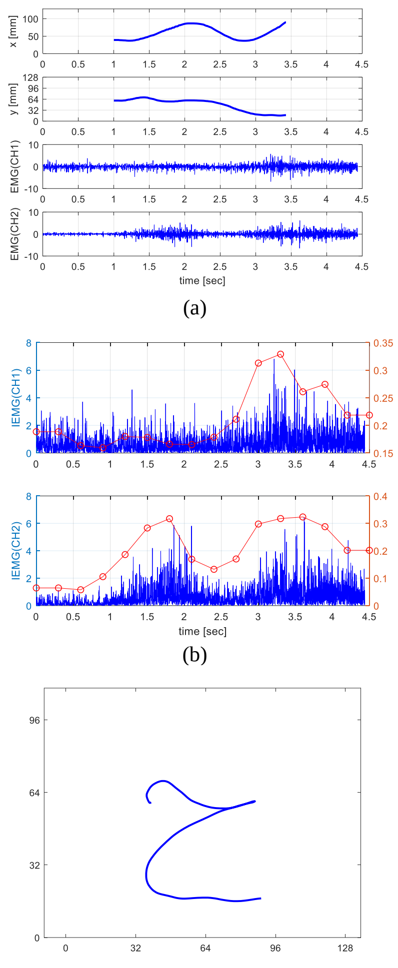

Figure 2. The letter, ح, «HA» (a) Movement on the plane (x,y) and EMG signals (b) integrated IEMG signals (c) Letter

This leads us to assimilate the hand as a robot with two degrees of freedom to generate handwriting on the plane.

3. Handwriting Prototype

Figure 3 presents the different steps to elaborate handwriting prototype based on the Bresenham control algorithm implemented in the FPGA field. In a first step, we recorded Integrated EMG (IEMG) signals, considered as inputs of block1 that presented the handwriting model developed in (Chihi et al, 2015), outputs of this block are the coordinates of the pen tip moving on the plane. As a second step, we use the estimated coordinates as inputs of the bi-axis control Bresenham algorithm, block 2.

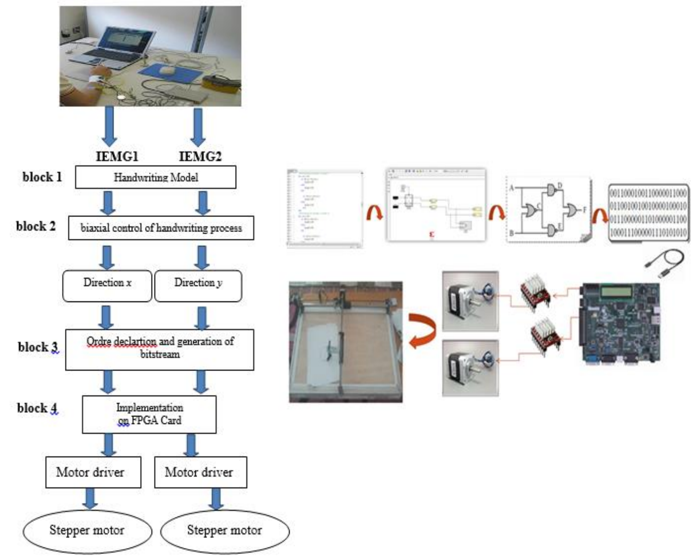

Figure 3. Synoptic schema of the proposed approach

From *x* and *y* directions, we develop control law on the Xilinx system generator, block 3. The computed *x*, *y* directions are sent to FPGA card, block 4, via a USB cable. This card will drive 2 stepper motors engines through the specific drive 4988A.

3.1. Proposed hardware-architecture

The design of the proposed built-in system can be presented in 06 parts:

- FPGA card, Spartan-3E used to implement the algorithms of command for drawing Arabic letters decoded in the language of description of very high-speed material (system generator),
- Electronic adapters,
- X-Y table with two stepper motors with step angle 1.8 deg and size 57x57x56 mm. It has four wires, each phase draws 2.8A, Voltage: 2.5V with holding torque 1.26 Nm (178.4oz.in). this device is designed by our team.
- Stepper motor, 23HS22-3006S.
- Stepper motor control circuit, A4988.
- PC used as a terminal for the configuration of the parameters and the display of the signals.

In this context, the FPGA with its big capacities of integration and reconfiguration makes a key component to quickly develop prototypes (Vetter and Schulz, 2014)and (Di Paolo Emilio, 2015).

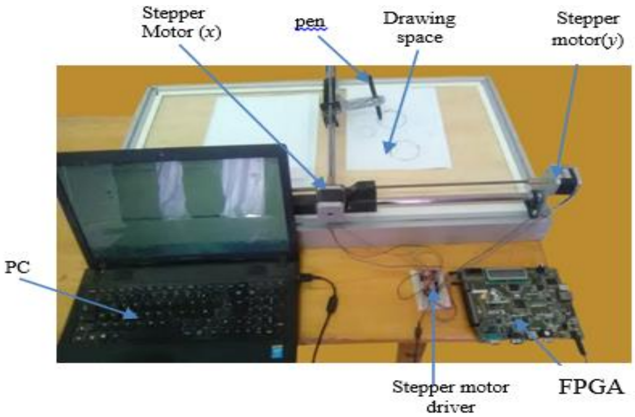

Figure 4. Proposed handwriting prototype

3.2. Embedded software architecture

The proposed handwriting controller is based on the Bresenham algorithm to produce a pen tip moving in the XY-plane. This technique is considered as a geometric controller, based on a circle, C, function, presented by equation (1).

$$F_c(x,y,R)=x^2+y^2-R \quad (1)$$

Where R is the radius of *C* and *O(0,0)* is the center.

Each point *M(x,y)* is deduced from two points *M1(x+1,y)* and *M2(x+1,y-1)*, this depends on the error sign calculated to select the position of the midpoint K between two points M1 and M2. If point K is inside the circle then the point M2 (x+*1,y-1)* is chosen. If *K* is outside, the point *M1(x+1,y)* is selected. Bresenham function uses two points: a starting point with coordinates (x_0,y_0) and an endpoint with coordinates (*x,y*). Tracing the Bresenham circle is to follow the path of the FPGA mathematical circle. The distances, *dx*, and *dy* are calculated between x_0 and *x*, and between y_0 and *y*, respectively.

A decision parameter "*p*" is calculated as follows:

$$p = 2 * dy-dx \quad (2)$$

We propose *Dy* and *Dx* as follows:

$$Dy=2*dy \quad (3)$$
$$Dx=2*(dy-dx) \quad (4)$$

The procedure starts with tracing the starting point (x1,y1) then continues with the other points depending on the decision parameter "p".

If "p" is negative, "p" becomes (p+Dy) and we advance with the abscissa (x = x +1) and this point is plotted. If "p" is positive then (y = y +1) and (x = x+1), "p" becomes (p + Dx) and we plot the point. We repeat the same process (dx-1) time, (Bresenham, 1965).

4. Simulation and Implementation Results

There is a wide gap between control system designers and FPGA-based implementation. In this regard, system-level design tools, such as Xilinx System Generator (XSG), seem to be a practical solution. Contrary to the design based on high-level languages, it provides a graphical user interface and automatic conversion into Very High-level Design Language (VHDL), code, which significantly reduces the design cycle [27].

The whole system is synthesized and downloaded on the FPGA card and the necessary rearrangements are made. Figure 5 shows electric control orders generated to two stepper-motors, assuring pen displacements according to x and y directions. This figure presents also the adequacy between MATLAB and XSG simulations control signals.

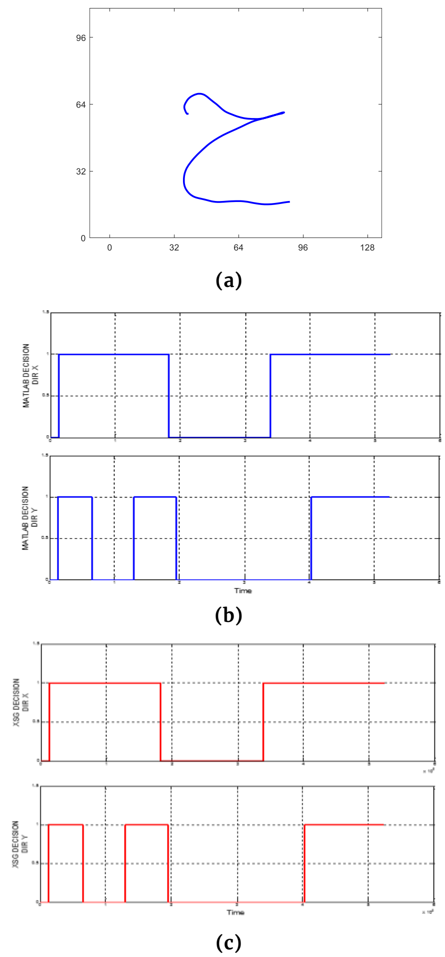

Figure 5. Simulation signal control by the MATLAB and XSG simulator(corresponding to the letter HA " ح": (a) letter AYN, (b) Signals according to Matlab, (c) Signals according to XSG

XSG is a high-level abstraction tool that allows the design and test Digital Signal Processing (DSP) systems in MATLAB / SIMULINK environment before implementing them on actual FPGA. It allows testing with all the powerful simulation capabilities (reading, displaying, and writing data) of MATLAB / SIMULINK.

Once the signed model has achieved the desired performance by simulation, it can be run on a real FPGA by hardware/software co-simulation of MATLAB / SIMULINK.

The co-simulation block and its associated bitstream file are automatically generated by the XSG compilation. During co-simulation, the compiled model (bitstream file) is loaded and executed on hardware taking advantage of SIMULINK's flexible simulation environment. This tool reads the data from the letter file in SIMULINK and transmits it to the downloaded design on the FPGA board using the JTAG connection. It then returns the result of the classification (output) to SIMULINK for display or possibly for storage. The proposed hardware architecture for letter tracing has been successfully implemented on an FPGA chip. The step-by-step command signals for tracing the letters obtained by XSG are approximately the same as those obtained by MATLAB software.

5. Experimental results and discussion

The proposed algorithm is developed by the Xilinx block set and simulated by the Xilinx system generator by selecting the appropriate FPGA kit (Spartan3E). In this simulation work, theSpartan3E kit is selected with its package defined properly.

After the successful simulation, the obtained results from the system generator model are analyzed with the previous results obtained from the model developed by Simulink. The requirement of the successful Xilinx model reveals that if the Xilinx system generator model results are matching the results of the Simulink developed model then the Xilinx model is successfully developed and verified.

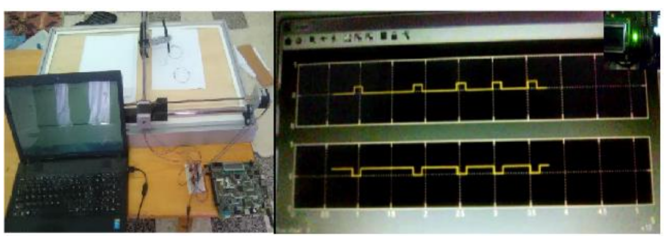

Figure 6. Generation of PWM signals

After the successful simulation, the obtained results from the system generator model are analyzed with the previous results obtained from the model developed by Simulink. The requirement of the successful Xilinx model reveals that if the Xilinx system generator model results are matching the results of the Simulink developed model then the Xilinx model is successfully developed and verified. Figure 6 shows two PWM signals for x and y directions.

Experimental results for Arabic letters, "AYN" and "HA", and the geometric form, circle are shown in figures 7 to 10. Indeed, figure 8 performs the letter "AYN" drawn by the proposed prototype (thick black line), and that recorded on the experimental basis (thin blue line). A considered error is observed especially in some parts of the letter. Figure 8 presents the comparison between two letters "HA", one generated by the prototype, and the other corresponds to the real recorded graphic trace. The proposed prototype imitates writing despite the complexity and the cursive characteristic of the chosen letters. Besides, it allows conserving the individual properties of the writer (preferential direction, inclination, etc).

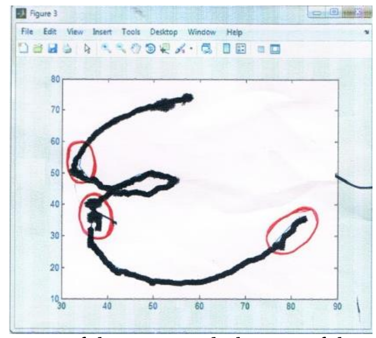

Figure 7. The response of the command: the case of the Arabic letter « AYN »

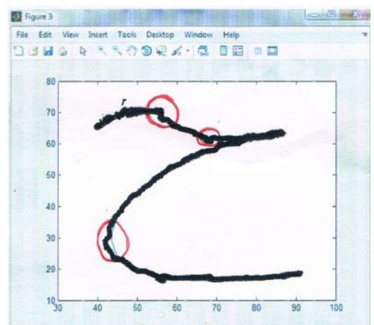

Figure 8. The response of the command: the case of the Arabic letter «HA»

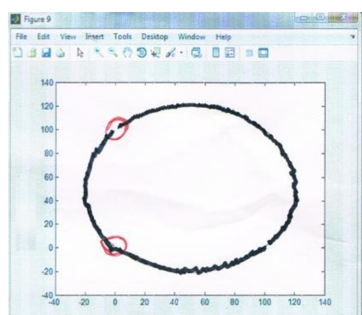

Figure 9. The response of the command: the case of geometric form, circle

For the geometric form case, shown in figure 9, the experimental result presents is in concordance with the real data, even the complexity of the studied shape. We can deduce that, at the level of very pronounced curvatures, the error becomes greater, which may be due to the speed of adaptation of the motor with respect to the change of the curvature. This can also be explained by some mechanical defects (system stability, friction, centralization of the axis) which are strongly linked to different mechanisms (mechanical guidance, movement transformation system, etc.).

6. Conclusions

The objective of the presented work was to analyze and highlight the contribution of FPGAs in the handwriting prototype. Simulation and experimental results are in accordance and show the efficiency of the Bresenham controller and the prototype design to imitate handwriting graphic traces. It turns out interesting to consider the third axis of movement to generalize the proposed in the case of the writing of words and sentences presenting diacritics.

References

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, 6337–6340.

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, 8,1:1–5.

Chihi I., Abdelkrim A. and Benrejeb M. (2012), Analysis of handwriting velocity to identify handwriting process from electromyographic signals, American Journal and Applied Sciences, 9,10:1742-1756.

Chihi I., Abdelkrim A. and Benrejeb M. (2017), Internal model Control to characterize human handwriting motion, International Arab Journal of Information Technology,14,6.

Plamondon R., Alimi A. M., Yergeau P.and Leelerc F. (1993), Modeling velocity profiles of rapid movements: a comparative study, Biol. Cybern, Springer, 69:119-128.

Fischer A. and Plamondon R. (2017), Signature Verification Based on the Kinematic Theory of Rapid Human Movements,in IEEE Transactions on Human-Machine Systems, 47, 2:169-180.

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, 30: 459-485.

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, 2819-2823.

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

Sano M., Kosaku T. and Murata Y. (2003), Modeling of human handwriting motion by electromyographic signals on forearm muscles, CCCT'03, Orlando-Florida.

Chihi I., Abdelkrim A.and Benrejeb M. (2015), Multi-model approach to characterize human handwriting motion, BiolCybern 110:17–30.

Chihi I. and Benrejeb M. (2018), Online Fault Detection Approach of Unpredictable Inputs: Application to Handwriting System, Hindawi, Complexity, 2018:1-12.

Chihi I., Sidhom L. and Maamri O. (2018), Robust Handwriting Estimator from Two Forearm Muscles Activities, International Journal of Applied Engineering Research, 13, 23:16213-16219.

Linderman M., Lebedev M.A. and Erlichman J.S. (2009), Recognition of handwriting from electromyography, PLoSONE 4:e6791,.

Okorokova E., Lebedev M., Linderman M. and Ossadtchi A. (2015), Adynamical model improves reconstruction of handwriting from multichannel electromyographic recordings, Frontiers in Neuroscience, 9: 1-15.

Li C., Ma Z., Yao L. and Zhang D. (2013), Improvements on emg-based handwriting recognition with dtw algorithm, IEEE Conference Engineering in Medicine and Biology Society (EMBC), of the (IEEE), 2144–2147.

Shilpa K. and Shriramwar S. S. (2009), FPGA-based Controller for a Mobile robot, IEEE International Journal of Computer Science and Information Security, IJCSIS, 3,

Martinez-Prado M., Franco-Gasca A., Herrera-Ruiz G., Soto-Dorantes O. (2013), Multiaxis motion controller for robotic applications implemented on an FPGA, International Journal of Advanced Manufacturing Technology, 67:2367–2376.

Vetter T., Schulz M. (2014), FPGA to Control Power Electronics, Power Electronics Europe, 6: 19-21,.

Di Paolo Emilio M. (2015), Embedded Systems Design for High-Speed Data Acquisition and Control, Springer.

Bresenham J.E. Algorithm for computer control of a digital plotter, IBM Systems Journal, 1965.