Analysis on motor control system based on DSP

Jie Luo, Wenchang Li, Huaxiang Lu

Abstract**—**DSP is a microprocessor commonly used in the design of motor control system, which is characterized by the advantages of strong data processing ability and fast running speed. This paper analyzes the design of motor control system based on DPS, including hardware design and software design. Hardware system structure, DPS main controller application, motor driver selection and communication circuit design are all analyzed; wherefrom the software design scheme, motor speed regulation method, the method of rotational speed measurement and the design method of SCI serial communication module are put forward, and finally the experimental verification to the system is conducted.

Keywords**—**DSP processor; motor control system; software and hardware design; system experiment.

I. INTRODUCTION

MULTI -motor control system has been widely applied in practical industrial production, including air-conditioning system, CNC system, robot, and so forth[1]. The DC motor utilized in the system has decent performance, with fast start-up speed, powerful anti-interference ability, and a wide range of speed regulation, which can realize stepless speed regulation[2]. With the continuous improvement of industrial production and automation, the performance requirement proposed for motor control system in industrial production has also been boosted up ceaselessly; and the coordination control of multiple motors needs to be handled[3]. Therefore, it is necessary to study the design of motor control system, thereby using the advantages of DSP microprocessor to improve the performance of the control system[4].

II. A BRIEF INTRODUCTION OF DSP MICROPROCESSOR

DSP is a type of mainstream microprocessor, which features higher running speed and data processing ability compared to the same type of processors, and is widely used in automatic control, industrial image processing, etc. In multi-motor motion control system, DPS is often utilized as system processor[5]; PC and DSP are designed as a main-sub structure, where PC is the upper computer of the system, and DSP is the lower computer of the system, which control the speed and steering of multiple motors[6]. The serial communication mode of the system provides the function of man-machine conversation, delivering a large amount of data operation to DSP for processing, and the motor driver completes the ultimate motor control operation. In the case of the synchronous control system of double DC motor, the system mainly has the functions covering synchronous speed regulation, steering and selection; the operator can set the speed and direction of the motor through the upper computer, transmit the data to DSP controller through RS232 serial port, produce the corresponding control signal, and finally use motor driver to complete the control operation[7].

III. SOFTWARE AND HARDWARE DESIGN OF MOTOR CONTROL SYSTEM BASED ON DSP

A. Hardware design

1. System composition and structure

The hardware system of motor control system based on DSP consists of PC, DSP, simulator, motor driver, DC motor and photoelectric encoder, and the system structure is shown in Figure 1[8].

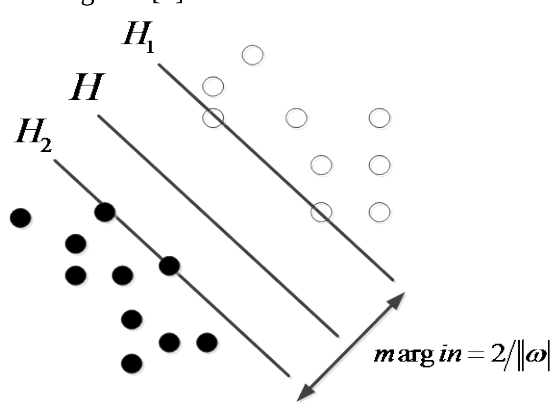


Fig. 1 Optimal classification plane schematic diagram

Wherein, the PC can communicate with the DSP, and on-line system program is debugged through the simulator. DSP can receive the set speed and direction parameters and generate corresponding control signals; two motor are controlled by independently-operated Motor Driver 1 and Motor Driver 2 synchronously, with the functions of speed

Jie Luo is with the Institute of Semiconductor, Chinese Academy of Sciences, Beijing 100083, China, and School of Microelectronics, University of Chinese Academy of Sciences, Beijing 100049, China.

Wenchang Li is with the Institute of Semiconductor, Chinese Academy of Sciences, Beijing 100083, China, and School of Microelectronics, University of Chinese Academy of Sciences, Beijing 100049, China.

Huaxiang Lu is with the Institute of Semiconductor, Chinese Academy of Sciences, Beijing 100083, China, and School of Microelectronics, University of Chinese Academy of Sciences, Beijing 100049, China. (corresponding author; e-mail: *luhx@semi.ac.cn)

regulation, commutation and motor selection[9]. Photoelectric encoder adopts the E6B2-CWZ3E Omron photoelectric encoder, whose resolution is 600P/R, which can meet the need of motor speed measurement. The motor applied in this design is 5D90GN-24 type, with the speed of 1800r/min, the power of 90W, and deceleration gear ratio of 180:1.

1 .DSP main controller

DPS main controller utilizes DSP chip, which is the 32-bit fixed-point chip provided by the TI Company, with decent cost-quality ratio, sound transaction processing capacity, digital signal processing capabilities and build-in control functions. TMS320F2812 chip uses Harvard Bus Architecture, and its data and program have different storage spaces; DSP's data processing rate is relatively high, the processor frequency can reach 150MHz, and its clock cycle is 6.67nsThis chip contains one 128KB flash and one 18KB RAM, with rich peripheral resources, which is conducive to reducing the hardware system's design difficulty. The business administration modules are two EVB, which can produce 4 independent PWM waveforms, suitable for various motor control, and support C language and C + + programming language.

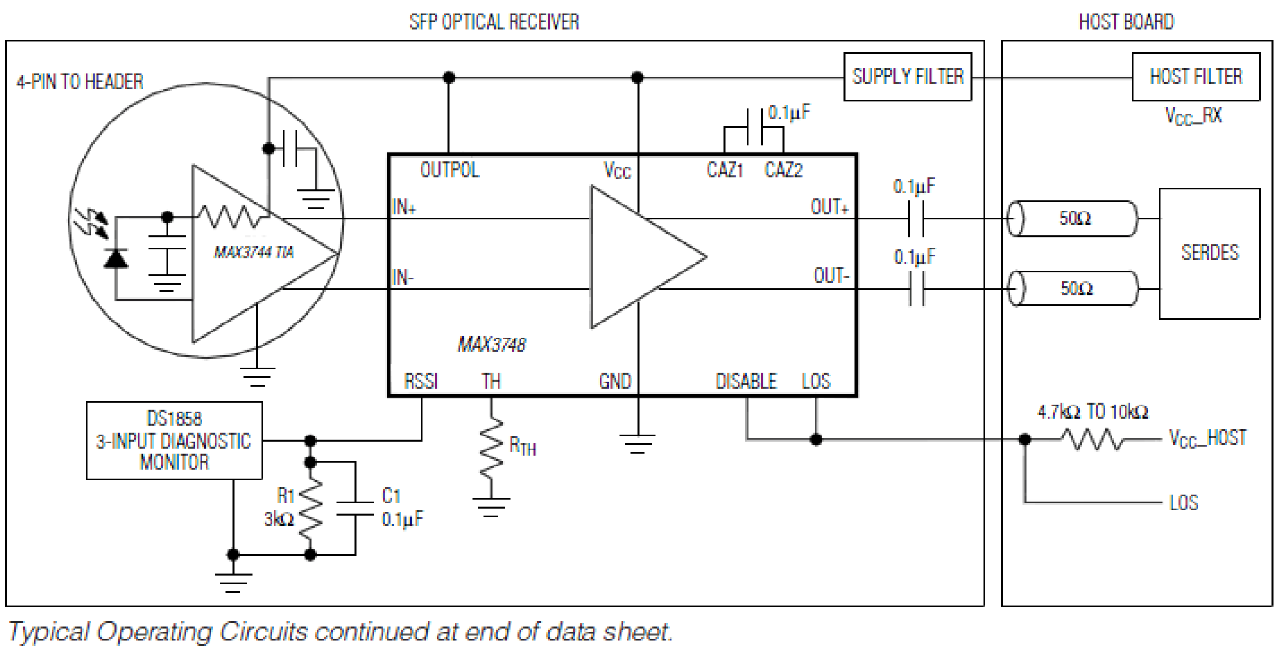


Fig. 2. Design model of communication interface circuit

2. The selection of motor driver

Motor driver is an important system component in controlling the motor to complete the action; it can perform the instructions of braking, acceleration, deceleration, and so forth. In this system, a total of two single-channel motor drives are set up, each channel of which can continuously output 16A current and drive the motor with 400W electric power to carry out operation. The motor driver contains overvoltage and overheat protection device, which can support the input of duty ratio. In addition, the photoelectric isolation to control signal can be carried out by optical coupling isolation HCPL0630 chip; with the compatibility to 3~5V voltage input, it has decent electromagnetic compatibility. In this system, one DSP chip is used to control two DC motors, of which the motor can be selected and controlled in terms of its speed and direction. At the same time, its running speed can be measured and displayed. The motor is controlled by four pins of GPIO A0, A1, A2 and A6, which correspond to 1NA, 1NB, Vcc and PWM of the motor drive respectively. H indicates high electrical level, L stands for low electrical level, X means the irrelevance to electrical level, and the motor operation logic principle is as shown in table 1.

Tab. 1 Logic principle of motor operation

Input Signal of drive control			Motor State in power output
1NA	1NB	PWM	
L	L	X	Brake
L	H	PWM	Forward rotation
H	L	PWM	Reverse rotation

For example, in the control process of M1 motor, the initialization function of the main program sets the aforesaid pin as a peripheral function, simultaneously, it carries out to set the timer 1; the symmetrical PWM wave is generated at the GPIO A6 pin, which controls the motor speed; and after the SCI data receives the interrupt signal, the register ACTRA is modified, which makes the GPIO A0, A1 and A2 pins' corresponding level to be (forced high/forced low), and then carry out the reversing control and selection to the motor.

3. Communication circuit

In order to realize the digital instruction control of double motor, it is necessary to establish the communication module between the upper computer and the lower computer; with this regard, serial communication port is adopted for design and achieving the goal. 2 signal lines are mainly utilized to achieve asynchronous serial communication interface, and standard MAX3232 chip on the basis of RS-232 is used to realize drive control. Serial communication module has 2 transceiver channels, and its circuit model is shown in Fig. 2, wherein the JP3 and the SCIA serial interface correspond to one another, which can be used for motor speed adjustment, motor reverse control, as well as motor selection control.

B. Software design

1. Overall design plan

In software system design, the main content of the design includes main program design, interrupt design of timer cycle, CAP capture interrupt design, SCI communication interrupt design, etc., the main program thereof is responsible for the comfort of the system and setting up peripheral modules and system global variables; the main program's workflow is as shown in table 2.

Tab. 2 Workflow of main program

Control Process No.	Control Content
1	System initialization
2	Global variables and module initialization
3	Wait for interrupt
4	Cycle
5	Interrupt service subroutine

In this system, the speed measurement of motor M1 mainly through the timer 2 cycle interruption and CAP3 capture interrupt realization, using T-method to speed up the clock pulse count, and calculate the speed. The speed measurement of motor M2 is realized by timer 3 cycle interruption and CAP6 capture interrupt, also using t method, the technology of high-frequency clock pulse is used to calculate the speed of motor M2 running. The main function of SCI communication interruption is to realize data exchange between PC and DSP main controller. All running programs are written in CCS6.0 environment, this software provides the fixed programming template of DSP module, its peripheral can find corresponding child function module. In the actual programming process, only need to add or modify the code in the template, the program design is easier to implement.

2, Motor speed adjustment

This system uses PWM (Pulse Width Modulation) to control and adjust the motor's rotation speed; this design method can realize the motor's stepless speed regulation, which belongs to speed control by constant torque. Under the condition of not changing PMW output wave frequency, by adjusting the ratio of the turn-on time and the period of armature voltage, the motor speed can be controlled, that is, control by the duty ratio D. The average voltage of both ends of the armature is U=V×D, and the duty ratio D= t1/T; PWM waveform is shown in Figure 3. In the system, the waveform of the PWM of the 2 motors is 20kHz symmetric PWM wave. Wherein, T1PWM duty ratio is realized by changing the value of the T1 CMPR, which is determined by the received data of interrupted SCI communication.

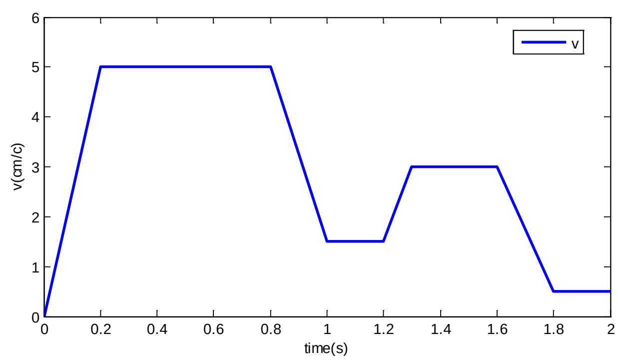


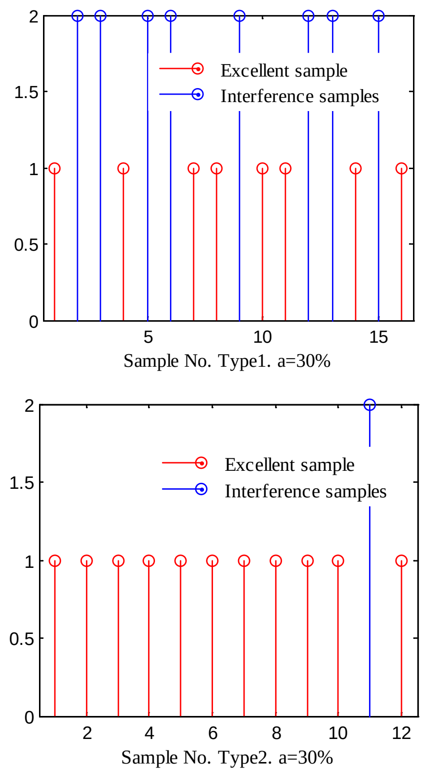
Fig. 3. PWM waveform diagram simulation

IV. MEASURING METHOD OF MOTOR SPEED

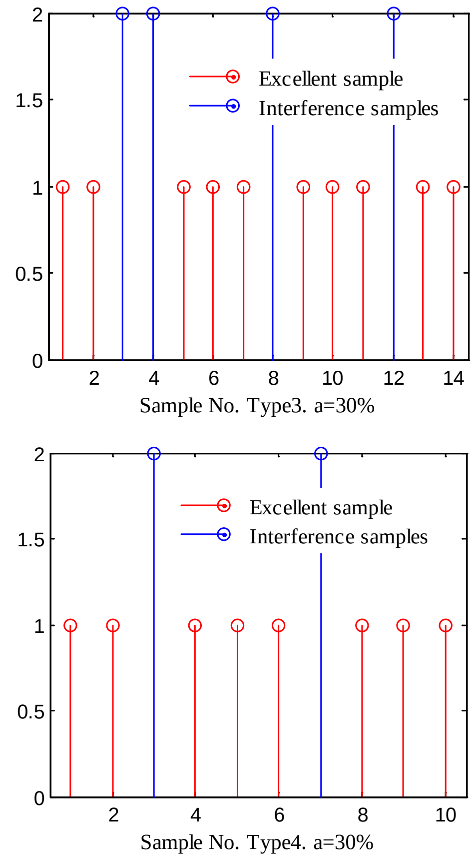
At present, the method of measuring motor speed mainly includes M method, T method and M/T method. Thereof M method is used to calculate the number of pulses emitted by photoelectric encoder in a sampling period, and the value is M1, and the speed of the motor is calculated by M1, which is also known as frequency measurement method. T method is to calculate the high-frequency clock pulse number in one pulse period, and its value is M2, and the speed of motor is calculated by M2, this method is also called cycle method. The M/T method is to calculate M1 and M2 at the same time, and use M1 and M2 to compute the speed of the motor. The characteristics of the three methods are shown in table 3.

Tab. 3 The comparison of three methods measuring rotational speed

Measuring method	Alternative Name	Objects to be counted	Features
M method	Frequency measuring method	Number of pulses emitted by photoelectric encoder	The number of pulses M1 is proportional to the speed of the motor; the measurement error is larger when the speed is lower; only suitable for high-speed measurement
T method	Period measuring	Number of high-frequenc y clock pulses	Suitable for low speed measurement only
M/T method	——	Number of pulses emitted by photoelectric encoder and number of high-frequenc y clock pulses	Can perform high detection precision in high-speed running state and low-speed running state, but it can't meet the demand of rapid response of system.



(a) (b)

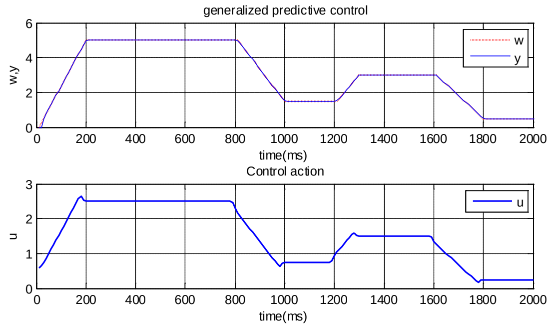


(c) (d)

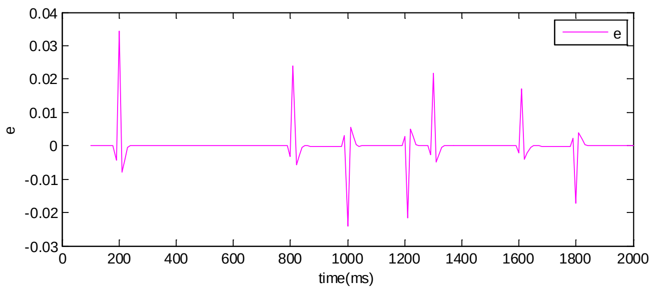
Fig. 4. Screening results of various categories of samples

(Fig. a shows the screening results under the fault type of high-energy discharge; Fig. b shows the screening results under the fault type of low-energy discharge; Fig. c shows the screening results under the fault type of high-temperature heating; Fig. d shows the screening results under the fault type of medium-and high-temperature heating)

As can be seen from table 3, the M/T method is applicable to the speed measurement of motor at both high speed and low speed, but the calculation speed is rather slow. This system applies DC deceleration motor, the torque is intense, the maximum speed is 1800r/min, the deceleration ratio is 180:1, and the drive axle’s output rotational speed is 10r/min; therefore, it is favorable to apply T method for speed measurement. Using the pulse edge of a period as the starting point and termination point of the technology, the main flow of the T method is shown in table 4.



(a)



(b)

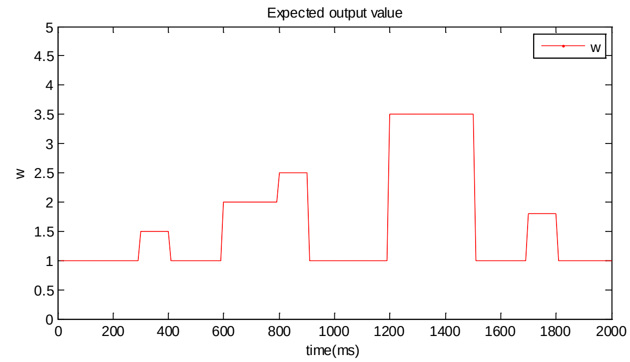
Fig. 5. Response results of working speed control

Tab. 4 Speed measurement flow by T method

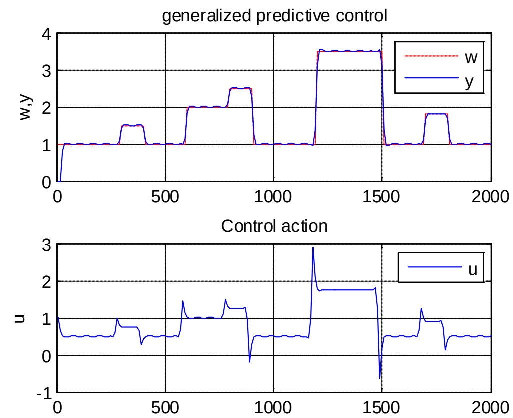
Speed Measurem ent Steps	Judging basis	Perform the operation
1	CAP61NT	Site protection
2	Whether cap6int is equal to 1	; Y: Read Cap6fifo value, and record t3pint value; N：cap6int++
3	Whether cap6int is equal to 2	Y: Read ap6fifo value, record t3pint value; N: Repeat judgmen
4	——	Speed calculation
5	——	Interrupt return

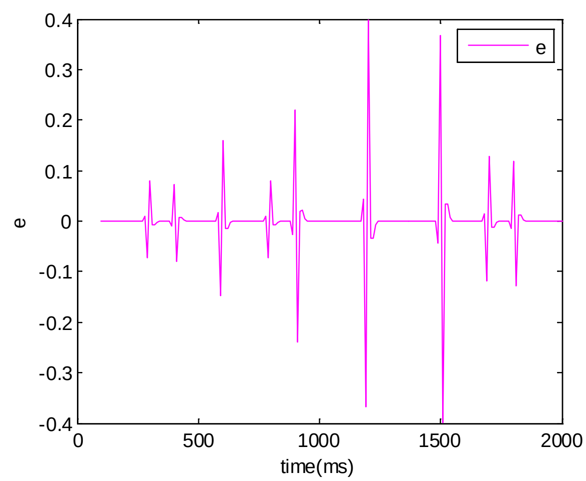
4, SCI serial communication module

In DSP2812, there are two serial communication modules, namely SCIA and SCIB; when communicating with the upper computer, the SCIA module is utilized to realize the data exchange between the PC, and the obtained value is assigned to the corresponding register, thereby realizing the motor control function. The module uses interrupts to receive data, and the interrupt flow is shown in table 5.



(a)





(b) (c)

Fig. 6. Response results of velocity control in step disturbance

Tab. 5 Terminal flow of data receive

Steps	Data receive interrupt flow
1	Protect the scene
2	Reading data from SCIRXBUF
3	To determine whether the reading is finished
4	Processing received data
5	Change the RICMPR value to adjust the speed. Change the ACTRA value for commutation and selection, then restore the scene
6	Turn on the interrupt

The serial port software of the upper computer sends 7-bit decimal data through com2; SCIA interrupt function receives data, store it in Scia_VarRx[i], and then compare the registers' values by changing Timer T1 through the numerical combination of the array, thereby realizing motor speed regulation. Also, through the data combination in the array, the numerical value is passed to the EVA CMCON register, so as to realize the commutation and selection of the motor. For example, the running states of the motor corresponding to the control word 243 are M1 and M2 forward rotation; and the running states of the motor corresponding to 252 are M1 and M2 reverse rotation. In addition, each element setting in the array is passed to the DPS global variable, and the global variable parameter changes can be seen in the software.

V. Experimental verification of motor control system based on DSP

Use the above scheme to design and realize the motor control system, and the hardware module is connected according to the physical connection diagram; the system can be tested and validated after normal startup. Input and send the control instruction "1125243" in the upper computer's serial port software, of which the DSP duty ratio is 40%; the PWM waveform diagram can be obtained, and at this time, the motors M1 and M2 are in forward rotation. By calculation, the theoretical rotational speed should be 4r/min; in the actual running process, the speed measurement is carried out by incremental photoelectric encoder, and the speed waveform is displayed in the CCS6.0 software. The experimental results show that the speed of the two motors rises from 0, and after the speed reaches the vicinity of the set value, the waveform fluctuates around the set value. Direction of the motor can be controlled by the serial port software, and the motor can be selected to achieve the expected design goal. The experimental results suggest that this system design can meet the function and performance requirement of motor control system with swift control of motor running parameter and high control precision. This can provide certain reference for the design of motor control system in practice.

VI. Conclusion

To sum up, the motor control system designed based on DSP can give full play to the advantages of DSP micro-processing, so that the control system is endowed with a strong data processing capacity and processing reaction speed. By analyzing the concrete design scheme of the hardware and software system, the key points of the system design can be defined. After the system design and experimental verification, it can be seen that the motor control system based on DSP is superior in performance and has relatively well-developed functions, which can meet the demand in practical application.

Reference

[1] Elsousy F F M. “Robust Recurrent Wavelet Interval Type-2 Fuzzy-Neural-Network Control for DSP-Based PMSM Servo Drive Systems”. *Journal of Power Electronics*, 2013, 13(1), pp. 139-160.

[2] Zaafouri A, Ben R C, Ben A H, et al. “DSP-based adaptive backstepping using the tracking errors for high-performance sensorless speed control of induction motor drive”. *Isa Transactions*, 2016, 60, pp. 333-347.

[3] Tekin A, Ata F, Gökbulut M. “Remote control laboratory for DSP-controlled induction motor drives”. *Computer Applications in Engineering Education*, 2012, 20(4), pp. 702–712.

[4] Diao L, Tang J, Loh P C, et al. “An Efficient DSP-FPGA-Based Implementation of Hybrid PWM for Electric Rail Traction Induction Motor Control”. *IEEE Transactions on Power Electronics*, 2017, 33(4), pp. 3276 - 3288.

[5] Zhu H, Li H. “Magnetic Field Equivalent Current Analysis-Based Radial Force Control for Bearingless Permanent Magnet Synchronous Motors”. *Energies*, 2015, 8(6), pp. 4920-4942.

[6] N. Li, L. Yan, H. Qian, et al. 1449. “Design and simulation analysis of an improved lower limb exoskeleton”. *Journal of Vibroengineering*, 2014, 16(7), pp. 3655-3664.

[7] Cai J, Deng Z. “A Position Sensorless Control of Switched Reluctance Motors Based on Phase Inductance Slope”. *Journal of Power Electronics*, 2013, 13(2), pp. 264-274.

[8] Rabie H, Arabi J, Mirzaeian Dehkordi B, et al. “Design and Implementation of the DSP-Based V/f Speed Control of an Induction Motor Using Intelligent Controllers”. *Investigational New Drugs*, 2012, 29(5), pp. 833-845.

[9] El-Sousy F F M. “Intelligent Optimal Recurrent Wavelet Elman Neural Network Control System for Permanent-Magnet Synchronous Motor Servo Drive”. *IEEE Transactions on Industrial Informatics*, 2013, 9(4), pp. 1986-2003.