Power and Electrical Engineering
2013 / 31

Micro Controller Unit Process Time Sharing and Digital Filter Analysis in Industrial Energy Exchange System

Marcis Prieditis[1], Davis Meike[2], Armands Senfelds[3], [1-3] *Riga Technical University*

***Abstract* — this paper provides an evaluation of control principles of power exchange modules used in industrial robotics. There is presented a detailed analysis of MCU computational time sharing between several time-critical functional processes and a digital sensor performance is experimentally validated. Measurements of overall control unit performance drop are done and possible system improvements are proposed.**

***Keywords* – energy efficiency, industrial robots, sensors, digital filters**

I. INTRODUCTION

Electrical energy consumption and respective costs are matter of high importance. Different energy saving activities is carried out in many levels of economical and geographical organizations. Target of saving 20% of primary energy by 2020 in comparison to 2007 has been set by EU [1]. Therefore, energy saving actions are considered by industrial energy consumers in EU. Automobile manufacturers in Europe are organizations that try to increase automation levels in their production lines as much as they can, which forces them to spend electrical energy more and more. Single car production chain including various production processes such as welding, handling, gluing, painting lead to a relatively large energy consumption [2]. Local research groups have been analysing energy saving possibilities and have concluded that great energy savings potential can be achieved, if energy recuperation would be introduced at factory level [3].

Energy recuperation system should eliminate braking energy dissipation through braking resistances in a DC bus of an industrial robot and save it in some sort of energy storage device, from which the energy could be acquired back later [4]. The proposed energy recuperation circuit consists of power part and control part.

The main task of power part (PP) is to provide energy transfer's environment that enables regenerative energy transfer to the energy accumulator and back to the robots. The main task of control part (CP) is to enable and control functionality of PP or disable it depending on system states. Different controlling algorithms can be implemented by the help of CP.

Although different topologies and variations of PP and CP are possible, one implementation of each has been practically built and used for experimental tests.

Experimental tests use a capacitor as an energy accumulator. These tests have also been carried out by the use of 2 KUKA industrial robots. Based on real testing environment requirements also CP of energy saving system has been built.

The next sections of this paper will present very general introduction in PP of energy saving system and deeper explanation of CP program architecture and sensor data processing mechanisms.

II. GENERAL DESCRIPTION OF POWER PART OF ENERGY SAVING SYSTEM

Although a future target of this project is to build energy saving system that is able to accommodate any electrical energy consumer device with built in DC bus, this project at its starting phase is focusing on KUKA type industrial robots. Usually KUKA robots consist of a manipulator, typically 6 permanent magnet synchronous servo machines, drive system and a controller [5]. Robots used in a project have a built-in DC bus line which is used to power each inverter [2]. When motors are accelerating they are taking energy from DC bus, when they are braking, the energy is supplied back to the DC bus due to machine recuperation. During the acceleration process a voltage in a DC bus decreases and during the braking process its voltage rises. When it reaches 688 V, a braking resistance is connected in parallel with DC bus in order to dissipate braking energy [4].

The PP of energy saving circuit basically is set of modules that interface each robot in system with energy storage capacitor (Fig. 1). PP mod n stands for n-th PP module. In general more than 2 PP modules can be connected to C.

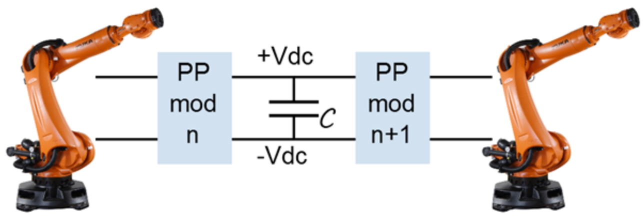

Fig. 1. Energy saving system and PP modules.

The version of PP modules that was used in tests does not enable CP to limit energy flow from robots to C. But the energy flow to the opposite direction can be limited.

Maximal voltage level in C can be greater than 688V, if energy flow to the robots is never enabled. If it is enabled constantly, than voltage level in C should follow voltage level in both DC bus systems [4].

III. Description of Control Part

CP is MCU based system that has voltage sensors on each DC bus (between robot and PP module) and C. It has also the industrial communication based inputs from robot controllers that inform of robot internal states. A HMI interface is also present.

Outputs are electrical signals that are driving IGBTs in PP modules and PROFINET data packets that inform of energy saving system and CP state. 16x2 symbols LCD is an output for user that is operating CP (Fig. 2, 4).

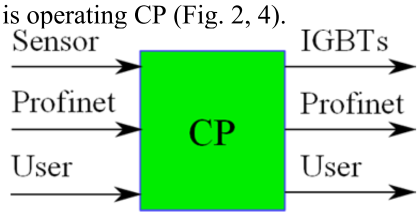

Fig. 2 CP inputs and outputs.

An actual CP that has been used in the tests is built up as a set of 3 modules:

1. Sensor input module (Fig. 3). This module contains 3 optical and 1 all-effect sensors, which enables voltage measurements of 2 DC buses, one capacitor module. It enables also a comparison of two sensor types.
2. A central data processing module (Fig. 4). This module contains MCU PIC24EP512GU810, which executes the main application algorithms. Part of user interface is implemented on it as an LCD and 3 pushbuttons.
3. A communications- and IGBT-control module (Fig. 5). This module has IGBT driver interfacing buffer ICs and device to handle industrial communication from HMS – Anybus Compact Com. This module is meant to work with Profinet IO communications protocol [6]. COM port communication is also possible through this module.
4.

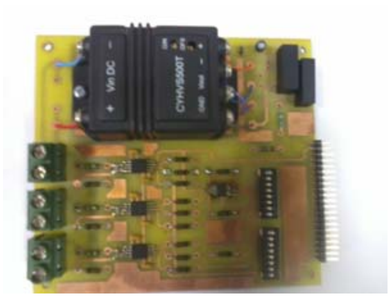

Fig. 3 Sensor input module.

Fig. 4 Central data processing module.

Fig. 5 Communications and IGBT control module.

IV. Processes of Control Part

CP has to implement 4 basic processes:

1. Sensor data processing
2. Communication with robots
3. User interface handling
4. Industrial process control (based on data acquired from previous 3 tasks).

All of the processes have their dedicated interrupt service routines which are executed at different frequencies and with different priorities depending on their influence on the overall algorithm. All of Interrupt Service Routine (ISR) handling mechanisms are the ones which are supported by currently used MCU PIC24EP512GP810 [8].

A. Separate process description

1) Sensor data processing

Due to the fact that CP's algorithm had to be designed for a quite noisy sensor input, digital filtering is present. Fact that a target MCU does not implement DSP capability did not initiate any use of Nyquist criterion for signal sampling and reproduction .[8] Instead was chosen strategy by which the ADC samples sensor inputs as often as possible and then moving average algorithm is used to implement low pass digital filtering.

CP that has been designed for the first tests implements 4 analogue inputs. Three of them are used to measure voltages on DC buses of robots and capacitor module, but fourth one was designed to enable comparison of different kind of sensors that can be connected in parallel with capacitor module's sensor. So that, MCU is configured to sample all 4 analogue inputs in 38 µs.

This time is fast if comparison is done with the time that is needed to apply simple moving average algorithm to 3 sensor inputs - 162µs (Fig. 6). Formula of moving average algorithm is shown here:

$$FV = FV + \frac{(JSV-FV)}{n}, \qquad (1)$$

Where FV is a filtered value, JS is a sampled value and n is number that states how many samples have to be averaged.

This type of moving average has some delay which depends on n. But on the other hand, higher n results in a less noisy averaged signal. Experimentally it has been tested that in case when ADC interrupt is called with 5 kHz (which is maximum possible frequency with target MCU and 4 analogue inputs) frequency than n with value of 400 satisfies energy saving process requirements. Of course, optimization should be done to get real value of needed n.

5 kHz makes ADC interrupt the most often interrupt in CP's algorithm, in comparison with rest of the ISRs. But this interrupt has to share MCU resources with other interrupts that are responsible for other processes, which reduces its actual frequency, which also will be calculated later.

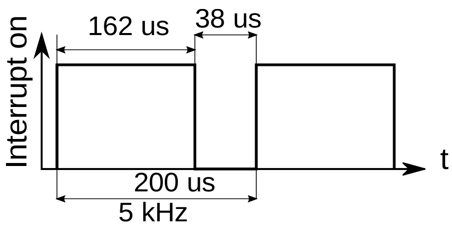

Fig. 6 ADC interrupt length and frequency.

2) Communication with robots

Communication with robots is done by the help of communications module that is able to work in Profinet network. Basically, the communication with robots is reduced to communication with Profinet interfacing module which is done by the help of UART module of MCU [6], [7].

This communication is done by the help of protocol that requires data packet sending and receiving with the minimum size of 19 bytes. Baud-rates can be adjusted to standard baud-rate values. Tests have been done with baud-rate of 19200 bytes per second and proved to satisfy requirements of industrial process. Of course, baud rate optimization can be done [3].

MCU built in DMA modules enables interrupt generation when full message of, for example, 19 bytes is received and not after each single received byte. When a message from communications module is received and interrupt bit has been triggered, a processing of received message starts. Sending and receiving is done by Direct Memory Access (DMA) and Universal Asynchronous Receiver/Transmitter (UART) modules [8].

Tests have shown that a message processing and response generation takes about 150 µs. And it happens with frequency of 33.67 Hz. That is because data sending to communications module, communications module data processing and data receiving takes about 29.7 ms (Fig. 7).

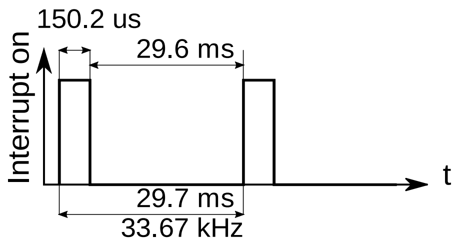

Fig. 7 Length and frequency of communication ISR.

3) User interface handling

User interface handling includes 2 things:

1. Setting and displaying system states;
2. Button press reading.

Both of them are implemented as routines that are called by some interrupt sources.

Setting and displaying system states is done about 2 times per second. Counting and interrupt calling is done by dedicated 16 bit timer. System states and display options are changed by taking into account button presses and dynamically changing data values.

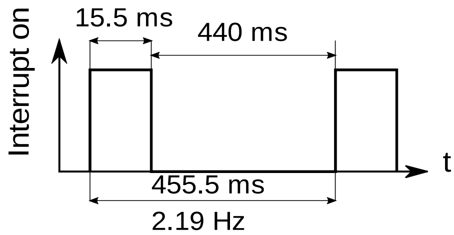

Fig. 8 Length and frequency of ISR which allows setting and displaying system states.

As shown in Fig. 8, an "interrupt on" time is larger than in previous 2 cases. That is mostly because of used FDCC1602N-RNNYBW-16LE display delay requirements after each command that has been sent to it.

Button presses are detected by dedicated interrupt and their values are used by previously described routine.

4) Industrial process control (based on data acquired from previous 3 tasks)

The interrupt of this process is called with frequency of about 3 kHz, because IGBT switches in power part of energy saving circuit does not need to be switched more often to satisfy industrial process requirements. Although process implements main logic of industrial process control algorithm, it is not doing too many calculations, only ready for processing data are compared to each other, new values to variables are given and signals are sent to IGBT and connector driver pins. That is why the MCU time taken by this process does not exceed 12.18 µs (Fig. 9).

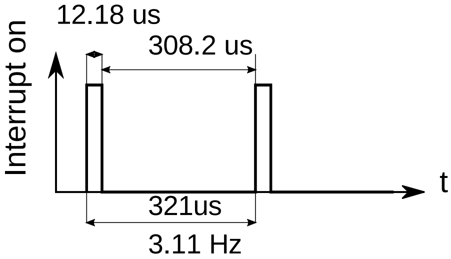

Fig. 9 Length and frequency of industrial process control ISR.

B. Process priority and sequence analysis

Industrial process control algorithm has been given the higher priority than rest of the processes that have been given lower but equal priorities. User interface process is composed of 2 interrupts. And to give user fast response, button responsible interrupt has been given the highest possible interrupt in system.

That means that button press can interrupt any of interrupt service routines that is being executed and industrial process control interrupt can interrupt rest of the system interrupt service routines (except button interrupts).

Rest of interrupt service routines are executed with their frequencies and if one is called during the execution time of the other, than it is executed immediately after previous execution has been finished.

Let's now consider 3 ISRs: Sensor data processing, communication with robots and GUI display and system variable responsible routine. All these routines have the same priority. If sensor data processing ISR is followed by communication ISR, than no delay in sensor data processing sequence is introduced, because communication ISR can be executed at 38 µs gap, which is used for ADC module to physically acquire voltage level at each input and not for sensor input data processing (Fig. 10).

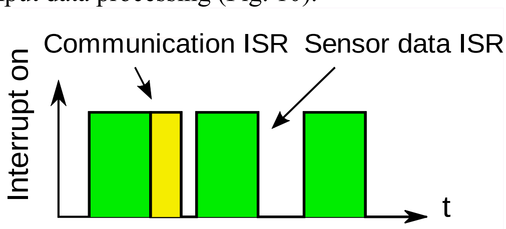

Fig. 10 Time sharing between Communication ISR and Sensor data processing ISR.

When a display-related interrupt is executed, a 38 µs gap in sensor data processing process is too short to fit in it 15.5 ms large ISR. That results in delayed sensor data execution time. Delay can be up to 15.5 ms + 150.2 us = 15.65 ms in case which is shown in Fig. 11.

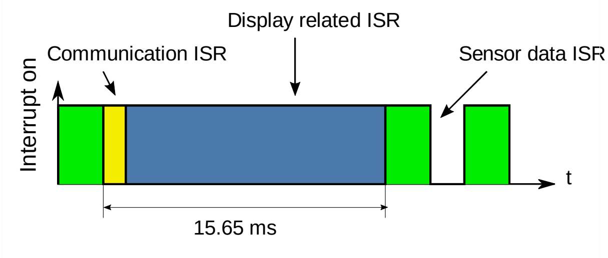

Fig. 11 Delay introduced by display related ISR.

As noted before, a display related ISR appears approximately 2 times in one second. And by taking into account this fact, minimum possible amount of sensor processing ISR executions in one second can be calculated as

$$f_{adc(\min)} = (1-2(T_{Dr}+T_{com}))\times f_{adc(set)} = \\ =(1-2(0.0155+0.000152))\times 5000 = 4.84kHz, \quad (2)$$

In the previous calculations $f_{adc(min)}$ is a minimum number of processed ADC ISRs per second, T_{com} is a length of communications ISR, T_{Dr} is display related ISR execution time.

$F_{adc(min)}$ is directly related to moving average algorithm. When 400 (practically tested and working value) values are averaged, than frequency that is related to this averaging period ($f_{MA(min)}$) is only

$$f_{MA(\min)} = \frac{f_{adc(\min)}}{MA_{samples}} = \frac{4.84kHz}{400} = 12Hz, \quad (3)$$

MA – is short form of moving average.

When any of these processes is interrupted by any of the higher priority interrupts than $f_{MA(min)}$ still describes process of averaging well, because it is rounded down value.

IV. Digital Filter Related Process Control Delay

Data that is coming from voltage sensors is basically used to enable the use of regenerated energy or disable it. Current version of CP algorithm enables it when DC bus voltage of central capacitor module is higher than some constant predefined value (HIGHER_LIM) and disables it when voltage in capacitor drops below some constant predefined value (LOWER_LIM).

Delay time between actual voltage signal appearance at sensor input and detection time of it has to be measured in order to describe response time of voltage sensing mechanism.

Theoretical delay was measured by script written in MATLAB that corresponds to the one in real MCU. This script applies step signal to digital filter, with previously described parameters (Fig. 12).

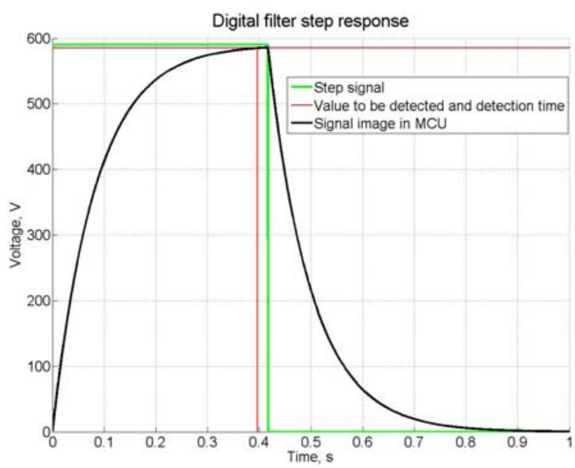

Fig. 12 Step signal applied to sensor input.

In the figure 12 step signal is green one. The length of it is time period that corresponds to digital filter averaging frequency – 12 Hz. It is a bit more than 0.4 seconds.

Black line shows how MCU “understands” step signal input.

Horizontal red line corresponds to some predefined voltage value, which detection delay time has to be measured. Vertical red line just helps to indicate crossing point of predefined voltage with MCU “understood” voltage level at its input.

In the Fig. 12 a predefined voltage level (red horizontal line) is set to 590 V. And output of the simulation shows that it was detected with delay of approximately 0.4 seconds.

In the practical experiments was very important to detect 585 V, which was set as UPPER_LIM. Depending on actual impulse length and amplitude this UPPER_LIM value can be missed or detected by MCU sooner or later. Table which uses impulse length of 0.4 seconds, shows 3 different UPPER_LIM detection delay times at 3 different impulse amplitudes.

TABLE 1.

UPPER_LIM (585 V) DETECTION DELAY TIMES WITH DIFFERENT STEP SIGNAL AMPLITUDES, BUT CONSTANT LENGTH - 0.4 S.

Pulse amplitude (V)	**UPPER_LIM detection time (s)**
590	0.40
640	0.20
688	0.16

If pulse amplitude would be 585 V, a more than 0.4 seconds of step signal width would be needed to detect this voltage on sensor input. Furthermore, if a pulse with would be shorter, than previously described impulses may not even be detected.

Although delay times are long, and some of pulses can even not be detected, industrial process, can be successfully completed without any losses in energy savings.

The reason why this happens is that a central capacitor works as an energy accumulator where braking energy is being fed in until voltage in it reaches UPPER_LIM. Sensor inputs are scanning just rising voltage in central capacitor unit. And even if UPPER_LIM is detected a bit later, than nothing bad happens – regenerated energy can be used just a bit later.

Long delay times in LOWER_LIM detection may cause some problems in system functionality, because one robot can start to power the other even if it needs energy to itself. Presence of this situation was not measured in practical experiments that have been carried out. But even if it was present, no error messages were generated by robots that were connected to the system. That means that even if this situation was present, than company that has developed these robots have designed their systems to allow energy transfers in this case [7].

V. CONCLUSION

Well functioning multi-process managing architecture has been implemented on PIC24EP512GU810. Analysis and tests has proven that it is adequate to use it for the implementation of supervising algorithm in energy saving system.

Designed program architecture still can be improved by analysing possible effects on lower moving average sample amount. This research may lead to possibility of Nyquist criterion use and lower sensor input sampling frequency that would leave more time to MCU for other tasks or sleeping mode.

Important outcome is fact that amount of saved energy in case of two test robots in system does not change even if sensor delay time is 0.4 seconds. Such a delay time may influence the amount of saved energy in case of more robots, since voltage could change more rapidly in central capacitor. Also smaller capacitance value of central capacitor unit could reduce amount of saved energy when large delay times are present during sensor data processing.

Less noisy sensor input would lead to reduced moving average sample amount. Therefore optimization could be done also in CP electronic design.

REFERENCES

[1] W.E.B.Wesselink, R.Harmsen, *How to triple the impact of energy saving policies in europe*, September 2010

[2] A.Burnham, J.L.Sullivan, M.Wang, *Energy-consumption and carbon emission analysis of vehicle and component manufacturing*, September 2010.

[3] T. Jordan, P. A. Taylor, *Hacktivism and Cyberwars: Rebels with a cause?* London: Routledge, 2004.

[4] R. Hayes, G. Pisano, D. Upton, S. Wheelwright, *Operations, Strategy, and Technology: Pursuing the competitive edge*. Hoboken, NJ Wiley, 2005.

[5] T. J. van Weert, R. K. Munro, Eds., *Informatics and the Digital Society: Social, ethical and cognitive issues: IFIP TC3/WG3.1&3.2 Open Conference on Social, Ethical and Cognitive Issues of Informatics and ICT*, July 22-26, 2002, Dortmund, Germany. Boston: Kluwer Academic, 2003.

[6] K. E. Elliott, C.M. Greene, "*A local adaptive protocol*," Argonne National Laboratory, Argonne, France, Tech. Rep. 916-1010-BB, 1997.

[7] K. Kimura, A. Lipeles, "*Fuzzy controller component*," U. S. Patent 14,860,040, December 14, 1996.

Marcis Prieditis received B.Sc. degree in electrical engineering from Riga Technical University, Riga, Latvia, in 2010. Planning to get M.Sc. in Spring of 2013. Currently is member of research team that puts efforts on efficiency improvement in industrial robotics.

Works at Institute of Industrial Electronics and Electrical Engineering as laboratory assistant.

Address: Kronvalda 1, Riga, LV 1048.

Phone +371 26065753, e-mail: marcis.priedite@rtu.lv

Davis Meike received M.Sc. degree in electrical engineering from Riga Technical University, Riga, Latvia, in 2008 and 2010, respectively.

He is presently a researcher at Daimler AG branch of Automation and Control Engineering, team Robotics and Technology Units, Sindelfingen, Germany.

He is Dr.Sc. student at Riga Technical University and a member of IEEE Robotics and Automation Society. His research interests include robot modelling, intelligent control systems, energy efficient path planning, logical and energetic cooperation of industrial robots, robotized production planning. Address: Kronvalda 1, Riga, LV 1048, e-mail:davis.meike@rtu.lv

Armands Senfelds received B.Sc.eng. of Riga Technical University, Latvia and M.Sc of RWTH Aachen University, Germany at 2009 and 2012, respectively at field of Electrical Power engineering.

He is a PhD student and research assistant at Riga Technical university, Institute of Industrial electronics and Electrical engineering.

He is a member of IEEE Power Electronics, Power and Energy Societies.

His research interests include intelligent design and control of power electronics and electrical drives, future power distribution systems with renewable energy integration and storage as well as electrical vehicles. Address: Kronvalda 1, Riga, LV 1048, e-mail:armands.senfelds@rtu.lv

Mārcis Priedītis, Dāvis Meike, Armands Šenfelds. Mikrokontrolera resursu sadalīšana laikā vairākiem procesiem un digitālā filtra izpēte industriālā enerģijas taupīšanas iekārtā.

Elektroenerģijas taupīšana sāk ieņemt arvien lielāku lomu, kā mājsaimniecības ierīcēs, tā arī industriālās ražošanas ietaisēs. Eiropas plāni 2020. gadam paredz, ka vēlamais enerģijas ietaupījums, sasniegs 20% no enerģijas patēriņa projekcijām 2020. gadā, kas tika izstrādātas 2007. gadā. Līdz ar to par enerģijas taupīšanu sāk domāt arī automobiļu ražotāji. Rakstā ir aprakstīts enerģijas taupīšanas princips, kas rāda, kā uzkrāt industriālo robotu bremzēšanas enerģiju kondensatoros. Uzkrāšanas un uzkrātās enerģijas atdošana tiek vadīta ar speciāla vadības moduļa palīdzību.

Vadības modulis ir bāzēts uz mikrokontrolleri. Tā ieejas signāli ir sprieguma līmeņi uz katra robota līdzstrāvas kopnēm un enerģijas uzkrājējkondensatora. Vadības modulis ir paredzēts darbībai Profinet IO tīklā, kas ļauj tam sazināties ar industriālajiem robotiem, vairāku robotu pārvaldības sistēmu, kā arī arī lietotāju. Darbība Profinet IO tīklā ir galvenokārt paredzēta industriālā procesa svarīgu mainīgo apmaiņai starp vadības moduli, robotiem un lietotāju.

Vadības modulim ir jāvar darbināt 4 paralēli procesi, kam katram ir savs uzdevums un prioritāte sistēmas vadībā. Visbiežāk izpildāmais process ir analogo ieeju skenēšana un noskenēto datu apstrāde. Tā notiek apmēram 4840 reizes sekundē un no tiem ir atkarīgs vai robotiem tiks atļauta reģenerētās enerģijas izmantošana vai nē. Pēc tam ieejas datiem tiek filtrēti ar digitālo filtru, kas ļauj atbrīvoties no trokšņiem. Digitālais filtrs ir viens no vienkāršākajiem zemfrekvenču filtru veidiem, kas izmanto slīdošās vidējās vērtības principu (*moving average*). Slīdošās vidējās vērtības filtra aizkavējums ir 0.4 s. Taču, par spīti tam, industriālā procesā ietaupītās enerģijas daudzums nemainās, jo uzkrājēj kondensatora kapacitāte ir pietiekami liela, kā arī sistēmā darbojošos robotu daudzums ir pietiekami mazs.

Izmantotajā vadības sistēmā, mikrokontrollera procesors ir noslogots gandrīz nepārtraukti, taču iespējams, ka tas varētu tikt atslogots, ja vairāk tiktu izpētīta digitālā filtra kvalitātes maiņa atkarībā no slīdošās vidējās vērtības vidējošanas intervāla.

Марцис Приедитис, Давис Мейке, Армандс Шенфелдс. Распределение ресурсов микроконтроллера для нескольких процессов и исследование дигитального фильтра для энергосберегающей установки.

Сбережение энергии занимает все более значимое место как для домашних, так и индустриальных электротехнических устройств. По планам Европы предполагается, что до 2020 года желаемое сбережение может достигнуть 20% от планированного в 2007 году объема потребления. В связи с этим и производители автомобильных средств начали работы по уменьшению расхода электроэнергии. В статье описан принцип реализации сбережения энергии в конденсаторах при торможении механизмов индустриальных роботов. Управление процессом сбережения осуществляется специальным модулем , который выполнен на базе микроконтроллера. Входные сигналы этого устройства являются характеристиками напряжений на общих шинах отдельных роботов и центрального энергонакапливающего конденсатора. Модуль управления предназначен для связи с индустриальной сетью Профинет 10, что позволяет реализовать связь между отдельными роботами, системой управления группой роботов и пользователем. Модуль управления должен координировать работу 4 параллельных процессов, каждому из которых установлен различный технологический алгоритм и приоритет при осуществлении управления. Наиболее частым процессом, выполняемым управляющим модулем, является сканирование входных сигналов и обработка этих показателей. Это проводится 4840 раз в секунду и от правильного функционирования зависит возможность рекуперации отдельным роботом. Входные данные фильтруются дигитальными фильтрами, что позволяет избавиться от различных помех. Дигитальный фильтр является одним из простейших видов низкочастотных фильтров, который использует принцип скользящего среднего значения. Задержка этого фильтра составляет 0,4 с. Несмотря на такую задержку в процессе работы она не оказывает влияние на параметры процесса рекуперации, что объясняется большой емкость накапливающего конденсатора и малым количеством роботов, подключенных к модулю. В данной системе модуль управления нагружен непрерывно, но возможно, усовершенствуя параметры фильтра, нагрузка модуля могла быть уменьшена.