ORIGINAL ARTICLE

Embedded Systems: An Alternative for Cuban Agroindustry Automation

Sistemas Embebidos: Una alternativa para la automatización de la agroindustria cubana

http://opn.to/a/otrXP

Ing. Lieter Javier Silva-Díaz [I] *, Dr.C. Yanoy Morejón-Mesa [II]

[I]Instituto de Ciencia Animal, San José de las Lajas, Mayabeque, Cuba.
[II]Universidad Agraria de La Habana, Facultad de Ciencias Técnicas, Centro de Mecanización Agropecuaria, San José de las Lajas, Mayabeque, Cuba.

ABSTRACT: Industrial automation is considered an essential part in the industrial development of a nation. In Cuba, specifically in the agricultural industry, the automation technology is obsolete and even in some cases it does not exist. This is mostly due to the difficult access to the technology and its high cost. In the present work, the development of own automation technology it is presented. It is based on embedded systems as an economically and adequate alternative for its use on the automation of the agricultural industry in Cuba. To achieve this, a search and comparison of the available automation technologies were realized. It took into account, the worldwide industrial technology traditionally used, which is based on Programmable Logic Controller (PLC) and the Supervisory Control and Data Acquisition, and the own technology based on embedded systems, developed for example, with a microcontroller. From the search and comparison, it was determined that the development of own technology based on embedded systems is more economical and is considered more adequate for the Cuban agricultural industry conditions.

Keywords: Agriculture, technology, automation, embedded systems, microcontroller.

RESUMEN: La automatización industrial se considera una etapa esencial en el desarrollo industrial de una nación. En Cuba, específicamente en el sector de la industria agropecuaria, la tecnología de automatización es obsoleta e incluso, en algunos casos, inexistente. Esto se debe fundamentalmente al difícil acceso a la tecnología y a su alto costo. En el presente trabajo se presenta el desarrollo de tecnología de automatización propia basada en sistemas embebidos, como una alternativa económicamente viable y adecuada para su uso en la automatización de la agroindustria en Cuba. Con este fin se realizó una búsqueda y comparación de las tecnologías de automatización disponibles, en la que se tuvo en cuenta la tecnología basada en Controladores Lógicos Programables (PLC) y Sistemas de Supervisión, Control y Adquisición de Datos (SCADA) que tradicionalmente se emplea en la industria a nivel mundial, y la tecnología propia basada en sistemas embebidos, desarrollada por ejemplo a partir de microcontroladores. De esta búsqueda y comparación se determinó que el desarrollo de tecnología propia a partir de sistemas embebidos resulta más económico y se considera más adecuado para las condiciones de la agroindustria cubana.

***Palabras clave*:** Agricultura, tecnología, automatización, sistemas embebidos, microcontrolador.

INTRODUCTION

Automation is the branch of technology that deals with the application of control systems to various human activities, mainly to industry. It is also defined as the action and effect of automating, that is, performing an act of production, distribution or government, without direct intervention of human conscience and will (Mataix, 2008).

Webster's online dictionary (http://www.websters-online-dictionary.org/definition/automation) defines automation as a highly technical implementation that usually involves hardware and electronic devices to replace human beings with machines in some tasks.

*Author for correspondence: Lieter Javier Silva-Díaz, e-mail: lieter@ica.co.cu

Received: 15/02/2019
Accepted: 29/04/2019

Another definition is made by Groover (2016), who states that automation, strictly in the field of manufacturing, is the technology involved with the application of mechanical, electronic and computer-based systems to operate and control production.

These definitions, in a general way, coincide with the idea of the use of 'certain technology' to control a production process. In addition, the first two definitions include the concept of 'replacing humans by machines', with which it agrees, but it is necessary to add that this replacement is partial and is also done for the benefit of the worker, by avoiding the performance of dangerous and routine tasks.

From these elements, it can be stated that automation is the technology that includes physical elements, like mechanical elements, electronic and computer systems (hardware and software), and theoretical knowledge, such as control engineering. This technology is implemented in various human activities, mainly in industry, in order to replace the human being in repetitive and tedious activities, which require great precision and speed or which could be dangerous or harmful to his life, leaving him a role where he can take much more advantage of his intellect, for example, as a supervisor.

The automation of industrial processes, including the agricultural industry, is a widespread practice worldwide, because it allows companies to increase their profits and competitiveness. Automation technology is expensive and some companies cannot acquire it. In the case of Cuba, the cost is not the only problem, because, even when the deficit of labor in agriculture could be solved by automation to increase production efficiency, the importation of these technologies is made difficult by the scope of the commercial, economic and financial embargo imposed by the United States government on Cuba.

The objective of this work was to propose an economical and adequate automation technology for Cuban agroindustry, considering the high costs of traditional automation technologies, the difficulty of acquiring them, the deficit of labor in agriculture and the need to develop it and its associated industry, to obtain products of high value added, suitable for consumption, exportation and tourism industry.

METHODS

A search on prices of technologies, both traditional and embedded systems is carried out on websites and commercial catalogs of some of the main manufacturers and suppliers of these technologies. In addition, a comparison is made fundamentally taking into account the economic cost. Several of the processors used in embedded systems based on their basic characteristics and their possibilities of use in the automation of the agroindustry are compared.

First, the benefits of automation in the industry are referred. According to Sharma (2017), some of the benefits of the use of automation in industrial processes are:

- Reduction of production losses.
- Resource optimization (saving of raw materials and energy).
- Higher safety, reliability and functional safety.
- Contribution to compliance with external regulatory requirements such as the environmental ones.
- Flexibility in control, allowing easy adaptation to other productions.

The use of automation in agribusiness could generate a group of benefits such as those previously mentioned. Among them, saving raw material, increasing energy efficiency and compliance with environmental standards are highlighted. Nevertheless, others like obtaining a product with greater added value, increasing economic benefits, competitiveness of companies and the possibility of filling the labor deficit in agricultural production must be incorporated.

Functional Safety

In every industrial or agroindustrial plant, the processes or machines that are operated suppose a certain level of risk for the integrity of the operators, the plant or the environment. This requires adopting security measures in order to efficiently reduce risks. These measures or tasks are controlled and implemented through the automation system and are called 'Security functions'. When protection systems are

implemented with automation systems, the most relevant international standard in terms of functional safety is IEC 61508, "Functional safety of electrical / electronic / programmable electronic systems related to safety". In addition to this basic standard, the specific standard IEC 61511 applies to the process industry (Smith y Simpson, 2016).

Functional safety, in some industries such as oil is mandatory, while in others that have fewer functional requirements, such as most applications of agro-industry, is only optional. Although, it is recommended for the benefits it provides such as the protection of plant personnel and equipment, when it is not a critical process in functional safety, that is, when it does not have high functional requirements, it is not commonly applied due to high costs.

Traditional Technology

The industrial solution to the problem of control of a process or plant includes the use of controllers such as Programmable Logic Controllers (PLC), and monitoring and / or monitoring systems, such as Supervisory Control and Data Acquisition Systems (SCADA).

Automation technology has a high cost, which includes the cost of the physical device, the software to configure, control and monitor these physical elements, whose cost is often higher than hardware, and training. In the opinion of the authors, the main difference between developed and developing countries is access to technology and the consequent technological dependence.

Embedded Systems

There are several definitions of embedded systems that are characterized by several specific features, such as the limited capacity of software and hardware compared to a PC, the number of functions to which they are dedicated and the reliability and security requirements (Noergaard, 2005). The same author and Holt and Huang (2018), refer the difficulty of defining the concept due to the evolution of it as a result of the constant advances in technology and the decrease in implementation costs.

For the amplitude of the concept, the one established by Noergaard (2005), is used. It defines an embedded system as a system with an applied computer, which is distinguished from other types of computers such as personal computers (PC) or supercomputers.

From this definition, and for the purposes of this work, it could be redefined as an electronic system, different from a personal computer, which uses a processor, such as the microprocessor of personal computers, in order to control a certain process.

Some of the available processors are:

- **Microprocessor**

Many of the embedded systems in real time use general purpose microprocessors. A microprocessor is a computer processor in an integrated circuit, which contains all, or most of the functions of the central processing unit (CPU) (Wang, 2017).

- **Microcontroller**

Compared to a general purpose microprocessor, a microcontroller is a self-sufficient system with peripherals, memory and a processor that is designed to perform specific tasks (Wang, 2017).

- **Digital Signal Processors (DSP)**

Digital signal processors (DSP) are designed for applications that require high calculation rates. DSPs implement algorithms in hardware offering high performance in repetitive calculation intensive tasks (Wang, 2017).

- **Field-Programmable Gate Array (FPGA)**

A Field Programmable Gate Array (FPGA) is a device that contains a network of cells or logic gates that can be quickly reconfigured, which facilitates the rapid creation of prototypes of embedded systems (Wang, 2017).

RESULTS AND DISCUSSION

Comparison of Processors for their Application in Agriculture

Microprocessor

Microprocessors find their applications when the tasks are not specific. For example, personal computers use these as a processor, which allows performing a variety of complex tasks such as software development, games, and websites. In these cases, the relationship between inputs and outputs is not defined. They need a lot of

resources, such as RAM, ROM and Input/Output (I /O) ports. Embedded software can be tailored to specific tasks that are designed for embedded systems.

Microcontroller

Microcontrollers are used in systems where the relationship between inputs and outputs are usually clearly defined. Some examples are: the computer mouse, washing machines, digital cameras, microwave ovens, cell phones and digital clocks. As the applications are very specific, they have little demand for resources such as RAM, ROM, I/O ports, and therefore can be embedded in a single chip with the processor. This reduces the size and the cost. A microcontroller is very easy to replace, while microprocessors are 10 times more expensive. In addition, microcontrollers generally consume less energy and are more immune to power peaks compared to other techniques (Wang, 2017).

Digital Signal Processors (DSP)

Digital signal processors are two to three times faster than signal processing applications based on general purpose microprocessors, including audio, video and communications. According to Wang (2017), among its disadvantages, it can be mentioned that they generally have a high cost and that some commercially available DSPs lack adequate support for the compiler.

Field-Programmable Gate Array (FPGA)

FPGAs are commonly used in the design stage and are usually replaced in the final product with custom circuits, due to higher performance and lower cost. When reconfiguration is an essential part of the functionality of an embedded system, FPGAs appear in the final product.

In the most common applications that require data processing, microprocessors, microcontrollers, DSP or FPGA are generally used. The microprocessors find their applications when the tasks are not specific. Microprocessor-based designs require a lot of resources, are complex and expensive compared to microcontrollers. Microcontrollers are self-sufficient systems with peripherals, memory and a processor that is designed to perform specific tasks. In the vast majority of cases, a design based on microcontroller is sufficient. In addition, it is simpler and less expensive than the microprocessor-based design. DSPs are used when it is necessary to implement certain algorithms in hardware, for example for signal processing, which allows higher processing speeds by decreasing the processor load. FPGAs are reconfigurable hardware, very expensive, which are generally used in the design stage of new products, but also and perhaps the most important application, is when reconfiguration is required in real time, which is an unusual requirement in the majority of the applications.

Particularly for control and automation applications in the agroindustrial sector, which do not have large processing and functional safety requirements, it is recommended to use microcontrollers over the microprocessor-based option, due to its simplicity and cost. When it is required to perform signal processing, which requires great processing power; it is recommended to use the DSP, since they implement some algorithms in hardware. Also, when reconfiguration is required in real time, an unusual requirement, it is recommended to use FPGA.

Embedded Systems in Agriculture Worldwide

Embedded systems have been widely used in various fields of agriculture. A study by Zhang & Pierce (2013) reported several applications during that year, as shown in Table 1.

Among the main results of the research process, Table 2 shows the prices of some of the products of SIEMENS*, a manufacturer of great prestige in the field of automation, and Table 3, those of some Microchip† microcontrollers, also a prestigious company and very popular among embedded system developers.

Table 4 compares the prices of some of the previously mentioned PLCs and microcontrollers.

It is necessary to clarify that the function of the microcontroller in the control system is to execute the control algorithms, so it can be considered as the 'core' of the system. In addition,

*Siemens is a registered trademark.
†Microchip is a registered trademark.

TABLE 1. Some reports of the use of embedded systems in agriculture during the year 2013

Application	Authors
Agricultural robotic vehicles	(Noguchi, 2013)
Agricultural infotronic systems	(Zhang *et al.*, 2013)
Precision agriculture	(Yang y Lee, 2013)
Automated crop production	(Shearer y Pitla, 2013)
Mechanization, monitoring and control in cotton production	(Sui y Thomasson, 2013)
Automated production in orchards and vineyards	(Burks *et al.*, 2013)
Automated enclosures and animal production	(Purswell y Gates, 2013)
Automation and nutrition management	(He *et al.*, 2013)
Automated pesticide application systems	(Karkee *et al.*, 2013)
Automated irrigation management	(Wang *et al.*, 2013)
Post-harvest automation	(Kondo y Kawamura, 2013)

TABLE 2. Selection of some low and medium-range PLCs (with software) (Siemens, 2016)

PLC	Characteristics	Price
LOGO! 8 12/24RCE	Simple Logical module LOGO! 8 12/24 RCE. LOGO! Soft Comfort V8.	241.66 USD
SIMATIC S7-1200 + KTP300 Basic	WinCC Basic V13 CPU 1212C AC/DC/RLY. KP300 Basic Mono PN. SIMATIC STEP 7 Basic V13 en el TIA Portal.	605.23 USD
SIMATIC S7-1200 + KTP700 Basic	CPU 1212C AC/DC/RLY. HMI KTP700 Basic Color PN. Step7 Basic.	1128.38 USD
SIMATIC S7-1511-1PN Compacto	SIMATIC S7-1500C, Compact CPU 1511C-1PN. Program memory: 175 KB, Data memory: 1 MB, 16 Digital Inputs, 16 Digital Output, 5 Analog Input, 2 Analog Output, 6 High speed Counters, Communication: PROFINET IRT. SIMATIC S7 - STEP 7 Professional V13 - TIA Portal Floating License	2281.25 USD

TABLE 3. Selection of some microchip microcontrollers (Microchip, 2017)

Microcontroller	Features	Price
PIC10F322	8-bit PIC MCU, Program memory: 0.896 KB, RAM memory: 64 b, Pin count: 6, Maximum CPU speed: 16 MHz, Converter channels A / D (Max.): 3 (8 bits) , Number of timers: 2 (8 bits), PWM outputs (Max.): 4 (10 bits)	$ 0.37
PIC16F18323	8-bit PIC MCU, Program memory: 3.5 KB Flash, RAM memory: 256 b, Pin count: 12, Maximum CPU speed: 32 MHz, Converter channels A / D (Max.): 5 (10 bits), Number of timers: 2 (8 bits) and 1 (16 bits), PWM outputs (Max.): 2 (10 bits) with CWG	$ 0.82
PIC18F97J94	8-bit PIC MCU, Memory: 128KB Flash, RAM Memory: 4KB, Pin Count: 100, Maximum CPU Speed: 64 MHz, Converter Channels A / D (Max.): 24 (10/12 bits), Number of timers: 4 (16 bits), PWM (Max.) Outputs: 7 (10 bits) with CWG, Communications: USB V2.0, SPI, I 2 C, USART (RS-485, RS-232 and LIN / J2602).	$ 3.56
PIC24FJ256GB406	16-bit PIC MCU, Memory: 256kB Flash, RAM Memory: 4KB, Pin Count: 64, Maximum CPU Speed: 32 MHz, A / D converter channels (Max.): 24 (10/12 bits), D / A converter channels: 1, Number of timers: 5 (16 bits), PWM outputs (Max.): 6 (16 bits) , Communications: I 2 C, SPI, UART, USART, LIN.	$ 3.87
PIC32MX110F016B	32-bit PIC MCU, Memory: Up to 128 KB Flash and 32 KB SRAM, Pin Count: 28, Maximum CPU Speed: 40 MHz, Converter Channels A / D (Max.): 10 (10 bits), Amount of timers: 5 (16 bits), PWM outputs (Max.): 6 (16 bits), Communications: USB, I 2 C, SPI, UART, USART.	$ 1.47
DSPIC33EP32MC202	16-bit dsPIC MCU, Memory : 32KB Flash RAM memory: 4KB, Pin count: 28, Maximum CPU speed: 40 MHz, Converter channels A / D (Max.): 6 (10/12 bits), Number of timers: 5 (16/32 bits) , PWM outputs (Max.): 6 (16 bits), Communications: CAN, I 2 C, SPI, UART, USART.	$ 1.44

TABLE 4. Price comparison

PLC	Price	Microcontroller	Price
LOGO! 8 12 / 24RCE	$ 241.66	PIC10F322	$ 0.37
SIMATIC S7-1200 + KTP300 Basic	$ 605.23	PIC18F97J94	$ 3.56
SIMATIC S7-1511-1PN Compact	$ 2281.25	DSPIC33EP32MC202	$ 1.44
SIMATIC S7-1200 + KTP700 Basic	$ 1128.38	PIC24FJ256GB406	$ 3.87
Average	$ 1064.13	Average	$ 2.31

it must be taken into account that this comparison is made considering only the cost of the processor.

As it can be seen, from the point of view of economic cost of the processor and for applications with low functional requirements, automation based on microcontrollers is much more economical than that used by traditional technology based on PLC and SCADA. This represents an alternative or opportunity to explore for developing countries or companies with low economic resources, and specifically for the Cuban agroindustry.

CONCLUSIONS

- A search and comparison of the available automation technologies was carried out, which took into account the technology based on Programmable Logic Controllers (PLC) and Supervision, Control and Data Acquisition Systems (SCADA) that is traditionally used in the industry worldwide, and technology based on embedded systems, developed for example from microcontrollers.

- It was determined that the development of proprietary technology from embedded systems is more economical and is considered more appropriate for the conditions of Cuban agribusiness.

REFERENCES

BURKS, T.; BULANON, D.; KYU, S.Y.; ZHIJIANG, N.; SUNDARARAJAN, A.: "Producción automatizada en huertos y viñedos", En: *Agricultural Automation: Fundamentals and Practices*, Ed. CRC Press Taylor & Francis Group, 2013, ISBN: 978-1-4398-8058-6.

GROOVER, M.P.: *Automation, production systems, and computer-integrated manufacturing*, no. solc. TS183 .G76 2008, Ed. Prentice Hall, 3rd ed ed., Upper Saddle River, N.J, 815 p., 2008, ISBN: 978-0-13-239321-8.

HE, Y.; LIU, F.; WU, D.: "Automatización y gestión de la nutrición", En: *Agricultural Automation: Fundamentals and Practices*, Ed. CRC Press Taylor & Francis Group, 2013, ISBN: 978-1-4398-8058-6.

HOLT, A.; HUANG, C.-Y.: *Embedded Operating Systems. A Practical Approach*, *[en línea]*, Ed. Springer International Publishing AG, 2.ª ed., London, 2018, ISBN: 978-3-319-72977-0, *Disponible en:* https://doi.org/10.1007/978-3-319-72977-0.

KARKEE, M.; STEWARD, B.; KRUCKEBERG, J.: "Sistemas automatizados de aplicación de pesticidas", En: *Agricultural Automation: Fundamentals and Practices*, Ed. CRC Press Taylor & Francis Group, 2013, ISBN: 978-1-4398-8058-6.

KONDO, N.; KAWAMURA, S.: "Automatización de pos-cosecha", En: *Agricultural Automation: Fundamentals and Practices*, Ed. CRC Press Taylor & Francis Group, 2013, ISBN: 978-1-4398-8058-6.

MATAIX LORDA, M.: *Diccionario de Electrónica, Informática y Energía Nuclear: Inglés-Español. Español-Inglés*, *[en línea]*, Ed. Ediciones Díaz de Santos, España, 2008, ISBN: 978-84-7978-411-9, *Disponible en:*Disponible en:https://library.biblioboard.com/content/bc283ab0-7ba8-474c-9b04-d35f16db1990 , *[Consulta: 11 de octubre de 2017]*.

MICROCHIP: *Microcontroladores PIC*, *[en línea]*, 2017, *Disponible en:* http://www.microchip.com/.

NOERGAARD, T.: *Embedded Systems Architecture: A Comprehensive Guide for Engineers and Programmers*, *[en línea]*, Ed. Elsevier Inc., 2005, ISBN: 0-7506-7792-9, *Disponible en:* http://www.books.elsevier.com.

NOGUCHI, N.: "Vehículos robóticos agrícolas", En: *Agricultural Automation: Fundamentals and Practices* , Ed. CRC Press Taylor & Francis Group, 2013, ISBN: 978-1-4398-8058-6.

PURSWELL, J.L.; GATES, R.S.: "Recintos automatizados y producción animal", En: *Agricultural Automation: Fundamentals and Practices* , Ed. CRC Press Taylor & Francis Group, 2013, ISBN: 978-1-4398-8058-6.

SHARMA, K.L.S.: *Overview of Industrial Process Automation*, 2017, ISBN: 978-0-12-809303-0.

SHEARER, S.A.; PITLA, S.K.: "Producción automatizada de cultivos", En: *Agricultural Automation: Fundamentals and Practices* , Ed. CRC Press Taylor & Francis Group, 2013, ISBN: 978-1-4398-8058-6.

SIEMENS: *SIEMENS SIMATIC Catálogo de ofertas de automatización 2025-2016*, *[en línea]*, 2016, *Disponible en:* http://www.siemens.es/simatic.

SMITH, D.J.; SIMPSON, K.G.: "The Meaning and Context of Safety Integrity Targets", *[en línea]*, En: *The Safety Critical Systems Handbook* (*Fourth Edition*), Ed. Butterworth-Heinemann, 4th ed., pp. 3-23, 2016, ISBN: 978-0-12-805121-4, *Disponible en:*Disponible en:https://www.sciencedirect.com/science/article/pii/B9780128051214000015 , *[Consulta: 7 de diciembre de 2017]*.

SUI, R.; THOMASSON, A.: "Mecanización, monitoreo y control en producción de algodón", En: *Agricultural Automation: Fundamentals and Practices* , Ed. CRC Press

Taylor & Francis Group, 2013, ISBN: 978-1-4398-8058-6.

WANG, D.; O'SHAUGHNESSY, S.A.; KING, B.: "Gestión automatizada del riego", En: *Agricultural Automation: Fundamentals and Practices* , Ed. CRC Press Taylor & Francis Group, 2013, ISBN: 978-1-4398-8058-6.

WANG, J.: *Real-Time Embedded Systems*, ser. Quantitative software engineering series, Ed. JohnWiley & Sons, Inc., 2017, ISBN: 978-1-119-42070-5.

YANG, C.; LEE, W.S.: "Agricultura de precisión", En: *Agricultural Automation: Fundamentals and Practices* , Ed. CRC Press Taylor & Francis Group, 2013, ISBN: 978-1-4398-8058-6.

ZHANG, Q.; PIERCE, F.J. (eds.): *Agricultural Automation: Fundamentals and Practices* , Ed. CRC Press Taylor & Francis Group, 2013, ISBN: 978-1-4398-8058-6.

ZHANG, Q.; SHAO, Y.; PIERCE, F.J.: "Sistemas infotrónicos agrícolas", En: *Agricultural Automation: Fundamentals and Practices* , Ed. CRC Press Taylor & Francis Group, 2013, ISBN: 978-1-4398-8058-6.

Lieter Javier Silva-Díaz, Investigador, Instituto de Ciencia Animal, San José de las Lajas, Carretera Central km 47½, Mayabeque. Cuba, e-mail: lieter@ica.co.cu
Yanoy Morejón-Mesa, Profesor Auxiliar, Universidad Agraria de La Habana, Facultad de Ciencias Técnicas, Centro de Mecanización Agropecuaria, San José de las Lajas, Mayabeque, Cuba, e-mail: ymm@unah.edu.cu

The authors of this work declare no conflict of interest.
This article is under license Creative Commons Attribution-NonCommercial 4.0 International (CC BY-NC 4.0)
The mention of commercial equipment marks, instruments or specific materials obeys identification purposes, there is not any promotional commitment related to them, neither for the authors nor for the editor.