Programmable devices applied to agriculture: Present and opportunity in the Boyacá region - Colombia

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Abstract*– This paper presents a review of the state of the art about the production and technological development of IoT appliances, based on the use of programmable devices (microcontrollers, microprocessors and DSP digital signal processors) in the agro-industrial sector of the department of Boyacá, in Colombia, as mainly in applications for smallholder agricultural production. A brief description of the issues faced by the agro-industrial sector of the department is addressed here, taking into account some considerations established by the Strategic Plan of Science, Technology and Innovation "PEDCTI Boyacá 2022". That is, science, technology and innovation STI at the service of regional development, addressing only milk, fruit and horticultural sectors, since they are the main agro-industrial chains in the region. Likewise, a procedure for searching and gathering information on IoT devices based on microcontrollers has been performed from well-known databases. Finally, a comprehensive review of STI capabilities is carried out in the universities of the department of Boyacá, which reveals a low technological production focused on agriculture, and a scarce amount of developments proposed mainly for scale or prototype deployment, without a real payoff in the sector.

***Keywords*-- Programmable devices, microcontrollers, agroindustry, Internet of Things, Colombia.**

I. Introduction

Traditional agriculture is transforming into smart agriculture due to the advent of the Internet of Things (IoT) technology. The IoT networks are reducing human labor requirements by monitoring the crops health and the field environment remotely. IoT uses a Wireless Sensor Network (WSN) as the backbone to collect information for these monitoring and control applications [1]. The monitoring-system consists of end devices equipped with a variety of sensors to monitor several crop parameters such as temperature, humidity, solar radiation, soil moisture, among others, and is capable of communicating this data to the other devices. IoT is helping farmers to monitor the crop growth stages, diseases, and yield prediction by giving them access to data using low-cost, low-power devices to increase processing capabilities over the Internet [2-3].

Traditionally, Boyacá has had an agricultural vocation of a smallholder nature, it is a region characterized by high soil fertility and a variety of climates. In agroindustry, Boyacá has historically had a weak structure and scarce social development around production systems. Likewise, its sustainability over time is limited because some factors such as the lack of industrial tradition, the absence of associative mechanisms and failures in the adoption of marketing strategies have delayed its development [4].

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"Agroindustry, as a sub-sector of the manufacturing industry, is projected as an important area for the economic development of Boyacá, given the increase in demand for fresh, semi-processed and processed foods by emerging economies. In Latin America there are external and internal technological differentials (gaps). The countries of Latin American and developed countries have taken as a reference the best international practices, in terms of capacities to absorb, imitate, adapt and innovate, with a view to adapting to the demand and the rapid evolution of technical change" [5].

Industrial globalization requires intelligent solutions, such as systems capable of monitoring tasks, decision-making, generating reports, improving processes and produce alert messages notifications [6]. Most industrial control systems use Programmable Logic Controllers (PLC), which are usually the most suitable controllers, but they are more expensive and harder to use [7,8]. An option that presents good prospects are microcontrollers, which are characterized by having a small working memory, low power consumption, low cost, several alternatives on the market, extensive documentation and development tools for low and high-level programming languages.

Furthermore, microcontrollers have been designed to interact with external storage elements such as secure digital cards (SD), real-time clocks (RTC) that provide precise time stamps for measured data, easy connectivity through RS232, I^2C and USB communication protocols, among other features, which make them highly applicable to the needs of the agricultural industry.

The content of this work is as follows, chapter 2 describes the study materials and methods, chapter 3 a review of the most used programmable devices is made, in chapter 4 an analysis of the agro industrial sector of Boyacá is carried out, chapter 5 provides a summary of IoT based Agro-industrial applications reported up to the day, the results of the study and its discussion are presented in Chapter 6, and finally, conclusions are shown in chapter 7.

II. Materials and Methods

This study was oriented in two approach lines, the characterization of the productive profile of the department of Boyacá in Colombia and the search for scientific publications related to the development of IoT applications in the agricultural sector. The study was considered only until 2019 to establish the diagnosis of the technological state of the department without the presence of graduates of the Electronic Engineering Program in the agroindustry of the region.

To guide the development of the study's first line of approach, the following research question was formulated: *¿How is technological development level in the agricultural sector of Boyacá through the use of programmable devices*? And to guide the second line of approach of the study, the following research question was posed: *¿What are the technologies used for IoT applications in the agricultural sector of the department of Boyacá*?

To answer the research questions, a systematic review of the available and affordable publications related to the development of IoT, microcontroller or DSP applications was carried out, focused on agricultural production in the Boyacá Region.

The SLR (Systematic Literature Review) literature search and review methodology proposed by Kitchenham and Charters [9-10] and performed by Talavera [11] was applied. Taking into account the results, it was possible to conclude that the three best sources of information for the topic of IoT for agro-industry and environment evaluated according to criteria of quantity, relevance and quality of information between 2014 and 2019 were Science Direct, IEEE Xplore, and Google Scholar. These three databases were chosen as reference sources.

For the bibliography search process, the following words were used in English: (*agricultural industry microcontroller*, *control system agricultural industry based microcontroller*, *monitoring system agricultural industry based microcontroller*) and in Spanish language: (*microcontroladores*, *aplicaciones en agroindustria*, *sistema de control agroindustrial* and *sistema de monitoreo basado en microcontrolador para la industria agrícola*). For each case, the total number of publications found was collected, then a search filter was applied. In this case by topic (use of microcontrollers in applications for the agro-industrial sector) and later a detailed review was made and provided to the reader in a summary form.

After applying the search equation in the three databases selected in the title, abstract, keywords and in any place of publication, 153 articles were listed. Non-agricultural studies and duplication of publications between databases were omitted. Once the information was collected, full text was available for 98 publications in the publication window between 2014 and 2019.

III. Programmable Devices

Programmable devices can be classified as programmable and programmable logic integrated circuits. A programmable device is an integrated circuit that contains a Central Processing Unit (CPU), memory units (RAM and ROM), input and output ports and peripherals. This classification includes microprocessors, microcontrollers and Digital Signal Processors (DSP). A Programmable Logic Device (PLD) is a general-purpose integrated circuit for implementing logic circuits, and it contains a set of logical circuit elements, which can be customized in different ways. In this classification, Complex PLD (CPLD) and Field Programmable Logic Arrays (FPGA) can be found.

A. Types of Devices

The use of digital devices for the measurement, monitoring and processes control is currently growing in such a way that nowadays control or instrumentation systems are not been devised without involving this type of device. Currently, the most widely used devices in this type of systems, which have a specific purpose and are part of a general category known as embedded systems, where the microprocessors are in first place and microcontrollers in second place, surpassing other devices such as DSP and FPGA [12].

The MicroProcessor Unit (MPU) is a logical integrated circuit that responds and processes logical and arithmetic operations; it contains thousands or millions of transistors, which are responsible for manipulating and saving the data to perform the programmed functions. In an overview, a microprocessor contains registers, a control unit, an arithmetic logic unit (ALU) and a math coprocessor [12].

On the other hand, the microcontroller is an integrated circuit that contains many of the same qualities as a desktop computer, such as the CPU, memory, etc., but does not include any human-machine communication device, such as a monitor, keyboard or mouse. “Microcontrollers are designed to be applied in the control of machines, instead of interacting with human beings” [12]. Their goal was to reduce costs and power consumption for particular applications, some features like amount of memory and peripheral options, depend on their purpose. Nowadays, microcontrollers are included in most household appliances and are widely used.

"The term DSP (Digital Signal Processor) applies to any chip that works with digitally represented signals. In practice, that term refers to microprocessors specifically designed to perform digital signal processing. DSPs use special architectures to accelerate the intense mathematical calculations involved in most real-time signal processing systems. For example, the DSP architectures include circuitry for the quick execution of Multiplication and Accumulation operations, known as MAC units" [12].

B. Review of IoT Applications

In a survey conducted by Talavera (2017) [11] at the Universidad Autónoma de Bucaramanga - Colombia, an updated review of IoT applications for the agro-industrial and environmental fields is presented. In this survey, a wide and methodical collection of works is reviewed, the author proposes a classification into four types of IoT applications for those fields, namely, Monitoring, Control, Prediction and Logistics. Likewise, the author highlights the identification of four layers in which it is possible to find technological developments based on IoT, these being the physical layer, communications, service and application as indicated in Fig. 1.

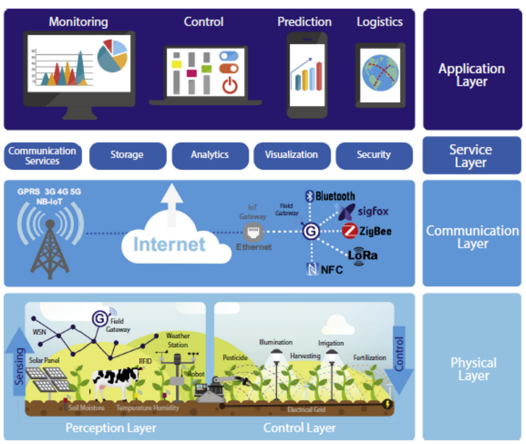

Fig. 1. IoT architecture for agro-industrial and environmental applications (Talavera, 2017).

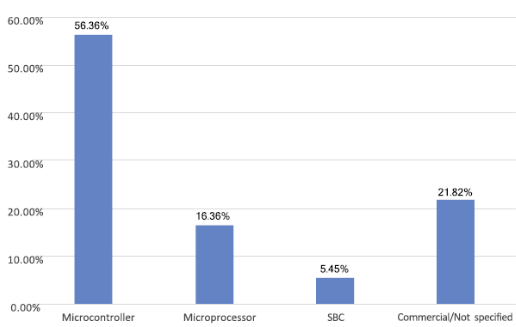

Fig. 2. Programmable devices used in IoT applications [11].

Otherwise, the author highlights that, of the total of works found, 56.36% correspond to developments performed by using microcontrollers, giving a clear vision of the applicability of these devices in IoT applications for the agro-industrial and environmental sector as shown in Fig. 2.

IV. AGRO-INDUSTRIAL SECTOR ANALYSIS IN BOYACÁ

The Gross Domestic Product (GDP) of Boyacá is useful for production of goods and services generated in the region and reflects its productive performance [13]. For the year 2010, the most productive sectors for the Boyacá´s GDP were the social services activities, agriculture, manufacturing industry, mining and quarrying, transportation, storage and communications, commerce and tourism as shown in Fig. 3.

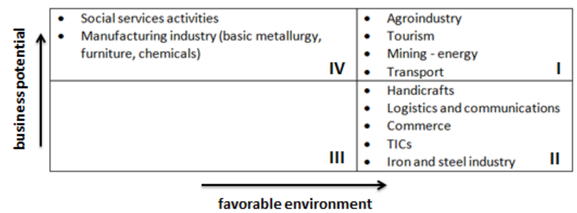

Fig. 3. Matrix of priorities by economic sectors of the department of Boyacá [4].

The main 26 products of the department by cultivated area are: potato, panela (brown sugar loaf), cane, corn, coffee, beans, peas, sugar cane, wheat, scallions, white onion, yucca, carrot, guava, cocoa, passion fruit, tomato, tobacco, lulo, arracacha (*Arracacia Xanthorriza*), tree tomato, blackberry, dragon fruit, cape gooseberry, early fig, and strawberry". The 19.2% of Boyacá's GDP corresponds to agricultural sector; the main chains are fruits, vegetables, cocoa, milk, goat, sheep, quinoa, panela, guava, cereals and legumes, hemp, coffee, potato, forest and aloe, among others [4].

In Boyacá, according to information provided from the Office of Agricultural Development, the most productive milk province producer is the west, which produces the 24.15% of the total production of fresh milk on the department, having only the 11% of cattle land. The next producer is the center province, with a production close to 23% using 21% of cattle land, and Tundama province, with a share in production of 18.3% [4].

The main problems identified in the Boyacá dairy chain are associated with low levels of competitiveness due to poor quality of livestock feed, genetic issues, low product safety management, infrastructure, some logistical failures in the cold chain, and inadequate technology in the gathering centres. Likewise, there are few companies that generate added value, because the production of dairy derivatives is accomplished through micro, small and medium-sized enterprises, most of which compete with large multinationals, greatly affecting the production and marketing costs [4].

The strength of Boyacá in fruit production is focused on perishables products (peach, plum, apple and pear), ranking second with 19% of the national production in 2010. Furthermore, there are some other products as citrus fruits, passion fruit, guava, tangerine, early fig, in a wide variety of crops [4].

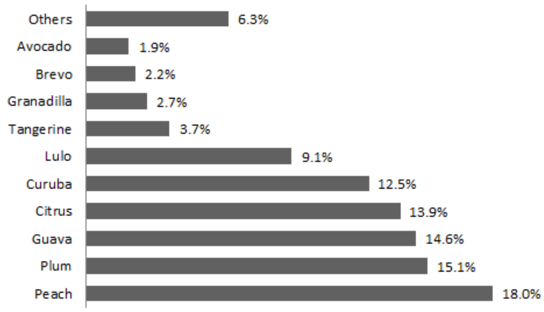

Fig. 4. Distribution of fruit production in Boyacá - 2010. (Adapted from [4])

Only 5.4% of the agro-industrial production of guava is destined to external market, and a similar result is expected for other fruit products. The main problems faced by the chain are similar to those of the rest of the agricultural fruit sector. These include: low level of training, high production costs, low level of added value, low capacity for technological adoption, deficiencies in road infrastructure and irrigation systems, high levels of intermediation, low crops yields, threats from pests and diseases, scarce linkage of the chain, low certification on both Good Agricultural Practices (GAP) and Good Manufacturing Practices (GMP), as well as phytosanitary certification issues. All those resulting in an incapacity to preserve through production cooling techniques, and so on [4].

Regarding the horticultural chain, only 0.5% of regional production is destined to international markets, with exports mainly to Venezuela, and some Caribbean Islands. According to data provided by the Office of Agricultural Development, in the horticultural chain, the department is strong in the production of onions, tomatoes, carrots, broccoli and cauliflower. The main problems identified in the chain are not far from the shortcomings of the agro-industrial sector as a whole, for instance: smuggling, legal growing of imported vegetables, high production costs, low variety and genetic quality of seeds, unsuitable and insufficient technological development, low support and access to real financing and technical assistance programs.

Likewise, precarious management capacities and ignorance of both national and external markets, obsolete techniques in soil management, high vulnerability to climate change, decrease in water sources and soil quality, high incidence of diseases and pests, low levels of aggregate value, and low producer prices as a result of high levels of intermediation [4]. The department is a traditional potato producer, ranks second in the country and uses an estimated cultivation area of approximately 37.370 ha. Not only has its production increased (776.426 tons in 2000 and 829.150 tons in 2010) but it also increased its yields from 16.2 ton/ha to 17.4 ton/ha during the same period; the average data is 18.9 ton/ha, characterized by a small-scale production: 95% occurs in units of less than 3ha.

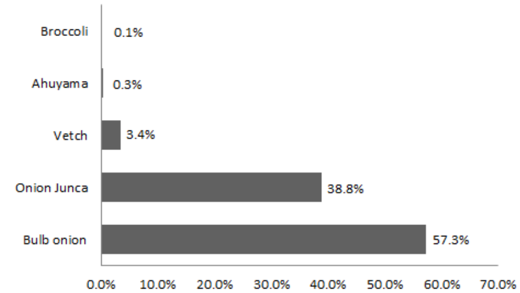

Figure 5. Distribution of the horticultural production in Boyacá - 2010. (Adapted from [4])

The main problems identified in this chain are obstacles in land title and ownership, inefficient irrigation infrastructure, vulnerability to climate change processes, low literacy level in the primary link of the production chain, and inefficient marketing systems with a high degree of intermediation. Furthermore, low linkage of qualified labor due to low ability to pay, low technical assistance in contrast with high supply of commercial assistance, low linkage level, the value-added generating industry only participates in 5% of the marketed potato, high incidence of smuggling, low application of both GAP and GMP and, therefore low levels of phytosanitary certification. Also, insufficient road infrastructure remains, weakness in the identification of new markets, misuse use of water sources, expansion of the agricultural frontier towards moorland regions, incidence of pests and diseases, poor waste management, among others [4].

A. Problems and Challenges

In the agricultural sector, mechanized jobs such us irrigation, agroindustry and specialized production imply high energy consumption, which makes it an additional high-cost input, affecting the profitability of producers. So far, none of the productive activities of the agricultural sector has used other types of energy or others alternatives [4].

In Boyacá, 48.51% of its population lives in rural areas, compared to 25% of the national total. A low-tech peasant economy with low levels of modernization still predominate, which negatively affects the competitiveness of the region and partially contributes to maintaining the department's high poverty rates. The farms that are currently being exploited by small producers present appreciable deficiencies in technology, technical assistance, planting planning and inadequate phytosanitary controls, besides poor value-added processes, lack of marketing, and insufficient irrigation and drainage infrastructure. These issues remain because the training and financial resources necessary for the implementation of technological packages that improve yields, profitability and competitiveness are not available [4].

"66.67% of the agro-industrial companies do not make investments in Research and Development (R&D). It may be due, in large part, to lack of funding (54.55%), lack of time for research (31.82%) and lack of knowledge on how to do research and new developments. This explains the reluctant behavior towards investment in science and technology, the limitations of departmental competitiveness and the fact that only 11.11% of companies have registered patents" [13].

In short, the agribusiness of the department of Boyacá follows the dispersed structure of a primary economy, with individual and isolated attempts to add value to primary products, scarce use of important technology in its industrial processes and low levels of insertion in the global market: its share in exports was 0.1% for the period 2009-2010 [4].

B. Access to PLD technologies in the region

Using the data collected from the annual survey, conducted by some companies such as Embedded Systems Design, EE Times and CMP Media LLC, among the subscribers of Embedded Systems Design, Embedded Systems Conference, EE Times and Embedded Systems Europe, it can be stated that the ten (10) leading manufacturers companies in the embedded systems market are Freescale™ (formerly Motorola), Intel®, Texas Instruments, Microchip®, Atmel®, Philips (now NXP Semiconductors), Xilinx®, Analog Devices™, IBM® and Altera®. The selection is made both by the use of their products, and by their good name among the developers of these systems (See Fig. 2).

Table I
Distributors for leading manufacturers in or near Colombia (CIDEI, 2008)

Manufacturer	Distributors	Web site
Freescale/ Motorola Intel	Richardson Electronics Colombia S.A.	http://www.rell.com/international/Colombia.asp
	ARROW - North Florida	http://www.arrownac.com
	AVNET - Clearwater	http://www.em.avnet.com
Texas Instruments Microchip	Plintec	http://www.plintec.com.co
	Ibars Electronics Corp	http://www.ibars.com
Atmel	Microchip Technology Inc	http://www.microchip.com
	All American Semiconductor	http://www.allamerican.com
	Atmel	http://www.atmel.com
Philips	Iprelenso Ltda.	http://www.iprelenso.com.co
Analog Devices	AVNET - Clearwater	http://www.em.avnet.com

Table I shows the list of distributors of the products of these companies in Colombia, if they exist there, or in the state of Florida, United States, where Colombian suppliers of electronic devices tend to be supplied [12].

V. Reported Agro-Industrial Applications Based IoT

As mentioned in section 2, the IEEE Xplore, Science Direct (Elsevier) and Google Scholar information databases were consulted. Furthermore, to carry out an analysis of the role of academic institutions in the region, part of this information was obtained from papers published by research groups from universities located in the department of Boyacá.

A. IEEE Xplore

In this information source ten publications were identified (filter applied: year 2014 to 2019) but only five of them are relevant to the query topic (use of microcontrollers in applications for the agro-industry sector). Table II shows the results of the process. Below is a brief description of the identified publications:

Safari, R. at the University of Science and Technology of Iran, presents a novel intelligent control for data management based on ATMEGA128 microcontroller. The proposed system is controlled by a powerful remote control using RFID technology, GPS / GPRS / GSM communication system and a data-logger mass storage system that can be used in agricultural industry and household consumption. In addition, the system can be synchronized with several liquid flow meters through the network, RS485, RS232 and M-BUS protocols in a secure and encrypted way. Furthermore, the implementation results show high efficiency and accuracy in data control with high resistance against data piracy [14].

Table II
Application of microcontrollers in the agroindustry using IEEE Xplore.

Search tool	Search Equation	Quantity of records	Relevance of the result	Date of search
IEEE Xplore Digital Library	Agricultural industry microcontrollers	4	3	7/20/2019
	Control system agricultural industry-based microcontroller	4	1	7/20/2019
	Monitoring system agricultural industry-based microcontroller	2	1	7/20/2019

Kishore, R. from the Electronics and Telecommunications Engineering Department of Warangal (India), develops a soil moisture-monitoring platform using IoT, considering that India is one of the 13 countries in the world with scarce water resources. It is a low-cost system for the control of a farm, which continuously measures the moisture level in the soil of plants and alerts farmers if the moisture content of certain plants is low through SMS or email [15].

Zainal, H. from Universiti Teknologi MARA of Penang (Malaysia), performs an automatic feeder for chickens to improve the chicken health, leading to high production of chicken meat and eggs. This helps improving environment conditions, while reducing the cost of labor, saving food and chicken feed in time, controlling the temperature for the freshness of the chicken feed and avoiding food contaminated by chicken feces, and insects [16].

Finally, Vasant, R., from the Technological University of Delhi (India), implements a system for acquiring environmental data in real time (temperature, humidity, light intensity and gas concentration) to facilitate the characterization of places for agriculture, industry and others related. The data is transmitted over WiFi and stored in the cloud [17].

B. *Science Direct (Elsevier)*

The results found in the Science Direct database (Elsevier) corresponding to the application of microcontrollers in control systems, monitoring and technification processes in the agroindustry, are shown in table 3. Fifty publications were identified (filter applied: year 2017 to 2019) but only five of them are relevant to the topic of consultation. Below is a brief description of the identified publications:

Abubakar, I. from the Universiti Teknologi Malaysia (UTM), proposes an application for charge monitoring in energy management to plan and minimize energy consumption. For monitoring procedures, it uses Intrusive Load Monitoring (ILM) and Non-Intrusive loading (NILM) techniques [18].

Table III
Application of microcontrollers in the agroindustry using ScienceDirect.

Search tool	Search Equation	Quantity of records	Relevance of the result	Date of search
ScienceDirect	Agricultural industry microcontrollers	18	5	7/20/2019
	Control system agricultural industry-based microcontroller	17	2	7/20/2019
	Monitoring system agricultural industry-based microcontroller	15	0	7/20/2019

Popovic, T. from the University of Donja Gorica (Montenegro), develops an IoT monitoring platform for precision agriculture. The platform can interact with various sensors, it also contains different communication protocols and is designed to handle various data storage media [19].

Tzounis, A. from the Department of Agricultural Production & Rural Environment of the University of Thessaly (Greece), reviews the increase in the demand for food, its quantity and quality, due to the necessary intensification and industrialization of the agricultural sector. They point out that Internet of Things is a technology capable to offering many solutions to modernize agriculture. Likewise, Cloud Computing and information analysis of "Big Data" information make it possible to automate processes, predict situations and improve many activities in real time [20].

Finally, Talavera, J. from the Autonomous University of Bucaramanga (Colombia) reviews the applications of the IoT in the agro-industrial field, encouraged by the need for identifying application areas, trends and architectures. He conducts technology surveillance using four approaches: monitoring, control, logistics and prediction. The collected insights reveal the fact that the IoT architecture represents a wide range of solutions to current problems of agro-industry [11].

C. *Google Scholar*

Table 4 shows the outcomes obtained from the search in the Google Scholar database, related to the application of microcontrollers in control systems, monitoring processes and technification processes in agroindustry. Ninety-three publications were identified (filter applied: year 2017 to 2019), but only eight are relevant to the topic of the query. Below is a brief description of the identified publications:

Monroy, O. from the Universidad Francisco de Paula Santander, Cúcuta (Colombia), describes a low-cost modular wireless system to monitor environmental variables in greenhouses. The system works with the ZigBee protocol and uses a wireless sensor network to collect information on relative humidity, temperature and brightness [21].

Rodríguez, E. from the Universidad Católica de Colombia (Bogotá), describes the development of an autonomous robotic prototype system for fumigation of tomato crops. The processing unit is a microcontroller and the development process is achieved through the use of C programming language [22].

Table IV
Application of microcontrollers in the agroindustry using Google Scholar.

Search tool	Search Equation	Quantity of records	Relevance of the result	Date of search
Google Academic	Microcontroladores AND Aplicaciones en agroindustria AND Colombia	16	2	7/20/2019
	Microcontroladores AND Sistema de control agroindustrial AND Colombia	22	1	7/20/2019
	Sistema de monitoreo basado en microcontrolador para la industria agrícola AND Colombia	55	5	7/20/2019

Other works related to the use of programmable devices, particularly microcontrollers, are those shown by Martínez. J., Orjuela, J., Valderrama, Y., Pulido, A., Burbano, C. and Martinez, A. [23-28].

D. *Capacities on science, technology and innovation in the department of Boyacá*

Taking into account the purpose of the universities of the department of Boyacá, whose main objective is to attend the needs of the environment, part of this survey is aimed at research groups recognized and categorized by Colciencias, observing which of them are currently developing control applications, instrumentation, monitoring and automation of agro-industrial processes.

The information registered in the GrupLac application for research groups was entered. The five main Universities in the Department of Boyacá are: Universidad Santo Tomas, Universidad Pedagógica y Tecnológica de Colombia UPTC, Universidad de Boyacá, Fundación Universitaria Juan de Castellanos and Universidad Antonio Nariño. The search for research groups is closely linked to the areas of knowledge of Electrical, Electronic and Computer Engineering, which range from 2015 to 2019. Table 5 summarizes the results retrieved, indicating the number of publications in the established period (Pub) and the number of relevant publications (Rel).

A total of 92 publications were identified, 6 of them relevant for pertaining to applications in Electronics, Control, information systems, robotics, intelligent systems and instrumentation applied to the agro-industrial sector. Below is a brief description of the identified publications:

Table V
Application of microcontrollers in the agroindustry using Google Scholar.

Institution	Research groups by knowledge area	Research lines	Pub	Rel
Universidad Santo Tomas Tunja	Grupo de Investigación y desarrollo de ingeniería en nuevas tecnologías GIDINT (*Classification B Colciencias*)	Instrumentation and Control	39	1
Universidad Pedagógica y Tecnológica de Colombia UPTC	Grupo de Investigación en Procesamiento de Señales DSP-UPTC (*Classification B Colciencias*)	Power Electronics Instrumentation and industrial automation Signals processing Agricultural technologies	12	1
	Grupo de Investigación en Robótica y Automatización Industrial GIRA (*Classification C*	Industrial automation Artificial intelligence Embedded systems Robotics	15	0
	I2E - Investigación en Ingeniería Electrónica (Reconocido)	Agronics Energy management	13	3
Fundación Universitaria Juan de Castellanos	Grupo de Investigación en Informática Avanzada – MUISCA (*Classification C Colciencias*)	WEB engineering Software process and control systems Informatics and information security Intelligent systems	9	0
Universidad Antonio Nariño	None in Boyacá	None	0	0

Source: Own elaboration.

Jiménez, A. from Universidad Pedagógica y Tecnológica de Colombia, performs a telemetry system, which contains an inertial measurement unit, a magnetometer, a pressure and altitude sensor, a GPS and two cameras. The objective of the system is to determine some vegetation indexes and generate three-dimensional crop maps [29].

Ruge, I. from Universidad Pedagógica y Tecnológica de Colombia, describes the results of a technological diagnostic process aimed at identifying the level of incorporation of programmable devices (microcontrollers) and programmable logic devices (CPLD and FPGA) in the production processes of the agro-industrial sector in the department of Boyacá. The diagnosis corresponds to the *panela* production sector, but makes interesting analyzes and discussions about the applicability of technology to close technological gaps in the department [5].

Likewise, Ruge, I. from the Universidad Pedagógica y Tecnológica de Colombia, describes the development of a microcontroller-based prototype for the monitoring livestock through a wireless monitoring network in order to prevent the cattle theft. The system is scalable to cover more livestock and a greater surveillance distance, covering a range of distance of up to 1.4 km [30].

Jiménez, F. from the Universidad Pedagógica y Tecnológica de Colombia, shows the development of Precision Index 1.0 PIND software, a useful tool for plant covers surveying (especially agricultural crops), as it takes advantage of the basic image processing analysis to recognize spatial-temporal patterns about what happen to plants in some phenological stages. Furthermore, this software platform makes it possible to evaluate the nutritional status of the crop and detect weeds and diseases [31].

Finally, Bellón, O. from the Universidad de Boyacá, describes the design process of a temperature controller that operates in discrete time, which aims to keep the interior of a greenhouse protected from the destructive effect of climatic frosts. The simulation result reveals that by using the two manipulated variables it is possible to perform efficient control actions to maintain the internal temperature of the greenhouse within a range to prevent frost damage [32].

VI. Results and Discussion

The results of the search and classification of publications related to the use of microcontrollers in the area of IoT with application in agroindustry reveal the existence of numerous publications, particularly in the Google Scholar database, as shown in Fig. 6. However, the Number of publications actually related to the topic of query is quite scarce. This result is quite striking considering the broad technical and economic advantages offered by the use of microcontrollers in IoT solutions, the results could indicate the use of other technologies that still remain in the prototype stage due to their complexity and cost, and perhaps may only be useful for large-scale agro-industry deployments.

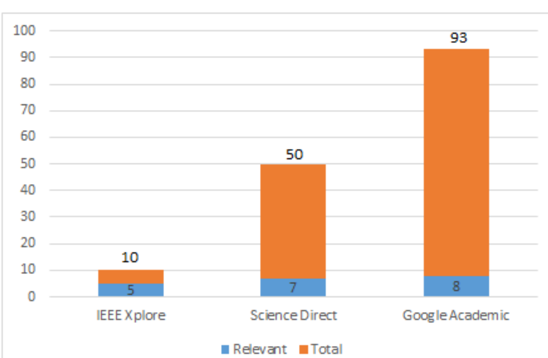

Figure 6. Publications found in databases.

It should also be noted the large percentage of relevance found in the IEEE Xplore database, which despite offering a smaller total number of records, provides relevance results in a half of them, these results confirm the search potential of this database for IoT issues found by Talavera [11].

The results of the analysis of scientific productivity in the region show a reduced number of publications for the search topics employed; these reveal a poor relation between the activities performed in the research groups and the needs of the agro-industrial sector of the department, as evidenced in Fig. 7.

These results can also lead to discussions about the usability of the results obtained from the IoT research work at the region.

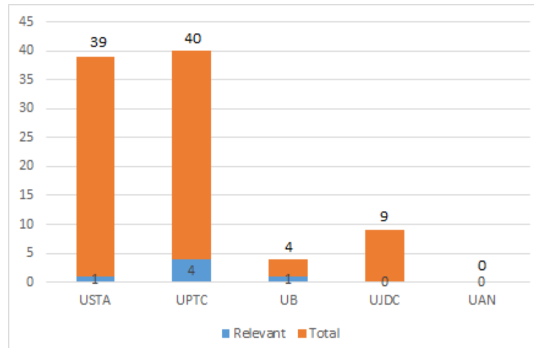

Fig. 7. Scientific publications of institutions in the region.

Any outline of a strategy to address the shortcomings found must begin with a comprehensive analysis of technology needs that in the region. Table VI summarizes some of the main problems faced by the agro-industrial sector in the department of Boyacá, identified by the "Observatorio en Ciencia y Tecnología" [4], where problems and challenges are pointed out and whose solution directions could be supported by the use of IoT solutions.

Table VI
Issues and challenges of the agro-industrial sector of Boyacá (PEDCTI, 2012)

Primary Production
• Land use with low levels of study and territorial planning. • Low integration of clean production processes. • Low levels of availability of statistical information. • Small and medium producers resistant to technological changes and use of new technologies.
Transformation
• Increased cost of supplies. • Scarce technological incorporation and innovation in the industry. • Basic or non-existent levels of use of waste and by-products for the generation of new products and cost reduction. • High disarticulation among sectoral, academic and state agents.
Commercialization
• Inadequate transportation and distribution logistics in terms of costs, times and assurance of product quality. • There are no information systems regarding monitoring and customer service in real time.
Final Consumer
• Greater demand in the quality and innocuity of the products.

Another important analysis accomplished by the aforementioned office, allows us to glimpse some susceptible areas to innovation in adoption of the use of IoT technologies for the agro-industrial sector of the region, as indicated in Table VII, whereas the potential for the developing applications based on microcontroller is evident, mainly in the primary production segment.

Table VII
Global trends for the agro-industrial sector in Boyacá (Boyacá Government, 2007).

Primary Production
• Remote sensors and satellite images for detection of physiological deficiencies and for the control and fumigation of weeds. • Robots and mechanization for harvesting and fertilization of fruits. • Requirements and soils suitable for cultivation. Yield increase per cultivated area. • Efficient (Technified) management of water resources.
Transformation
• Application of cleaner technologies and procedures. • Reduction of carbon dioxide (CO_2) emissions. • Employment of Territorial Credit Institute for process management. • Efficient usage of energy in profitable plants. • High link between sectoral, academic and state agents.
Commercialization
• Online information systems for cargo tracking. • Generation and promotion of products of origin (Brand Name). • Innovation in commercial strategies through social networks and new technologies.
Final Consumer
• Promotion of alternative energies from biomass and reuse of waste from harvest and post-harvest processes.

The choices for developing IoT applications include works such as the use of wireless sensor networks, crop monitoring using unmanned aerial vehicles (UAV), continuous recording of soil variables, prediction of weather and meteorological conditions and use of alternative energy sources [33]. However, some important considerations must be taken into account, mainly about economic factors, taking into account the predominance of small-scale agriculture and the predominance of smallholdings in the region [34]. These considerations could be a fundamental part to achieve the evolution of prototypes based on IoT towards truly usable solutions [35].

VII. Conclusions

As indicated in the so-called "Plan Estratégico Departamental de Ciencia, Tecnología e Innovación PEDCTI, Boyacá 2022", science, technology and innovation for helping the region, and the agro-industrial sector represents the highest priority for the department. However, the diffusion and development of technology focused on the agro-industrial sector, mainly carried out by the research groups of the regional universities is still lacking. There are a total amount of five universities located in the department of Boyacá, and all continue to offer Electronic Engineering programs, therefore, the ongoing efforts of these programs and their research groups continue to focus on solving problems, that are not relevant with the reality of the agricultural issues in the region.

The microcontroller chip is the most widely used programmable device in applications for the agro-industrial sector around the world, with the IoT architecture being the predominant one in these scenarios. There is a valuable opportunity for the Internet of Things concept to be harnessed by researchers, in order to satisfy the needs of the department, mainly supporting research and development activities in technology, primarily focused on the monitoring, control, prediction and logistics of agricultural processes. These initiatives could contribute to reduction of technological gaps, which are still present at main productive chains of the agricultural sector in the department of Boyacá.

References

[1] Zervopoulos, A.; Tsipis, A.; Alvanou, A.G.; Bezas, K.; Papamichail, A.; Vergis, S.; Stylidou, A.; Tsoumanis, G.; Komianos, V.; Koufoudakis, G.; Oikonomou, K. Wireless Sensor Network Synchronization for Precision Agriculture Applications. *Agriculture* 2020, *10*, 89.

[2] Heble, S., A. Kumar, K. V. Durga, and S. Samirana. A low power IoT network for smart agriculture. In *Proc. IEEE 4th World Forum on Internet of Things (WF-IoT)*, 609-614. Singapore.

[3] Ho, T.T.; Shimada, K. The Effects of Climate Smart Agriculture and Climate Change Adaptation on the Technical Efficiency of Rice Farming—An Empirical Study in the Mekong Delta of Vietnam. *Agriculture* 2019, *9*, 99

[4] Gobernación de Boyacá. 2007. Plan estratégico departamental de Ciencia, Tecnología e Innovación – PEDCTI. Available on http://ocyt.org.co/wp-content/uploads/2017/07/pedcti-boyaca.pdf.

[5] Ruge R., I.A., and W.J. Pérez H. 2017. Diagnóstico tecnológico del uso de dispositivos programables en la industria boyacense. Caso de estudio: cadena agroindustrial de la panela. *Revista Tecnura*, 21(52): 130-147.

[6] Sims, B.; Kienzle, J. Sustainable Agricultural Mechanization for Smallholders: What Is It and How Can We Implement It? *Agriculture* 2017, *7*, 50.

[7] Dangare, P. 2018. Design, fabrication and testing of a low cost Trunk Diameter Variation (TDV) measurement system based on an ATmega 328/P microcontroller. *Computers and Electronics in Agriculture*, 148: 197-206.

[8] Siddique, M.A.A.; Kim, W.-S.; Kim, Y.-S.; Kim, T.-J.; Choi, C.-H.; Lee, H.-J.; Chung, S.-O.; Kim, Y.-J. Effects of Temperatures and Viscosity of the Hydraulic Oils on the Proportional Valve for a Rice Transplanter Based on PID Control Algorithm. *Agriculture* 2020, *10*, 73.

[9] Kitchenham, B., Charters, S., 2007. Guidelines for performing systematic literature reviews in software engineering. In: EBSE Technical Report. EBSE-2007-01. pp.1–50.

[10] Garcia, P., J. León, L. Cardenas, and J.F. Giraldo. 2018. Modelado numérico del proceso de secado solar de manzanas en el municipio de nuevo Colón-Boyacá. *Rev. UIS Ing.*, 17(1): 201-208.

[11] Talavera, J. 2017. Review of IoT applications in agro-industrial and environmental fields, *Computers and Electronics in Agriculture*, 142: 283-297.

[12]Centro de investigación y desarrollo tecnológico de la industria electro electrónica e informática y la universidad de Cundinamarca CIDEI. 2008. Procesadores digitales de señal. Informe tipo vigilancia científico técnica. Proyecto apoyado por Colciencias código 329037019598.

[13]CREPIB. Boyacá. 2009. Agroindustria productiva y competitiva: Boletín N° 1. Tunja: Centro Regional de Gestión para la Productividad y la Innovación de Boyacá.

[14]Safari, R. 2017. An Innovative Smart Package for Liquid Flow Meters. In proc. 25th Iranian Conference on Electrical Engineering (lCEE2017), 158-163. Iran.

[15]Kishore, R. 2016. An IoT Based Soil Moisture Monitoring on Losant Platform. In *Proc. 2nd International Conference on Contemporary Computing and Informatics (ic3i).* 764-768. India.

[16]Zainal, H. C., M. H. Ismail, F. H. Otthaman, M. K. Safie. 2017. Development of Automatic Chicken Feeder using Arduino Uno. In *Proc. International Conference on Electrical, Electronics and System Engineering (ICEESE)*, 120-124. Kanazawa.

[17]Vasant, R. 2016. Real Time Standalone Data Acquisition System for Environmental Data. In Proc.1st IEEE International Conference on Power Electronics Intelligent Control and Energy Systems (ICPEICES-2016), 1-4. India

[18]Abubakar, I. 2017. Application of load monitoring in appliances' energy management – A review. *Renewable and Sustainable Energy Reviews*, 67: 235-245

[19]Popovic, T. 2017. Architecting an IoT-enabled platform for precision agriculture and ecological monitoring: A case study. *Computers and Electronics in Agriculture*, 140: 255-265.

[20]Tzounis, A. 2017. Internet of Things in agriculture, recent advances and future challenges, *Biosystems engineering*, 164: 31-48.

[21]Monroy, O. 2017. Sistema inalámbrico modular de bajo costo para supervisar variables ambientales en invernaderos: un respaldo al agricultor de pequeña escala. *Revista Científica*, 29(2): 164-179.

[22]Rodríguez, E., and M. Zabala. 2016. Desarrollo de sistema autónomo y Prototipo robótico para fumigación de cultivos de tomate. Universidad Católica de Colombia. Bogotá. Available on http://repository.ucatolica.edu.co/bitstream/10983/14719/3/Articulo.pdf.

[23]Martínez, J., and D. Pérez. (2017). Desarrollo de un Sistema de control para el riego y la iluminación de una granja vertical. B. Thesis. Dep. de Control y Automática, Universidad Autónoma de Occidente. Cali, Colombia. Available on: https://red.uao.edu.co/bitstream/10614/9782/1/T07449.pdf

[24]Orjuela, J. 2012. Desarrollo e implementación del diseño tecnológico para el proyecto de agricultura de precisión en un cultivo de tomate en Sutamarchán, Boyacá (Colombia). B. Thesis. Facultad de Ingeniería Electrónica, Universidad Santo Tomás. Bogotá, Colombia. Avalilable on: http://repository.usta.edu.co/bitstream/handle/11634/3448/OrjuelaLorena2012.pdf?sequence=1&isAllowed=y

[25]Valderrama, Y. 2017. Diseño e implementación de un instrumento electrónico de medida de pH para terreno agrícola. B. Thesis. Dept. de Ingeniería Electrónica. Universidad Nacional Abierta y a Distancia. Ibague, Colombia. Avalilable on http://repository.unad.edu.co/bitstream/10596/13356/1/1110464411.pdf

[26]Pulido, A., and E. Espitia. 2016. Diseño e implementación de un sistema de supervisión, monitoreo y control de temperatura, presión y tiempo de proceso en un sistema de digestión anaeróbia de biomasa (contenido ruminal bovino) a escala de laboratorio. B. Thesis. Facultad Tecnológica. Universidad Distrital Francisco José de Caldas. Bogotá, Colombia. Available on

[27]Burbano, C. 2017. Implementación de una red de sensores inalámbricos LPWAN mediante módulos lora para el monitoreo de la calidad del agua en 2 ríos. B. Thesis. Facultad de Ingeniería, Universidad Distrital Francisco José de Caldas. Bogotá, Colombia.

[28]Martínez, A., and D. Garcia. 2017. Prototipo de máquina empacadora de productos hortofrutícolas. B. Thesis. Dep. de Automática y Electrónica, Universidad Autónoma de Occidente. Cali, Colombia.

[29]Jiménez, A.F., J. M. Salamanca, M. J. Quiroz Medina and O. E. Acevedo Pérez. 2015. Diagnóstico de Cultivos Utilizando Procesamiento Digital de Imágenes y Tecnologías de Agricultura de Precisión. *INGE CUC*, 11(1): 63-71.

[30]Ruge Ruge, I., F. Jiménez López, and O. Hernández Gómez. 2016. Prototipo de sistema de vigilancia de ganado usando red de supervisión inalámbrica para prevención de abigeato. *Ingenio Magno*, 7(2): 87-101.

[31]Jiménez, F., A.F. Jiménez, and D. García R. 2015. Software para el estudio de coberturas vegetales con conceptos de agricultura de precisión. *Ingenio Magno*, 6: 128-139.

[32]Bellon, O., H. Amador, and E. Rodríguez. 2016. Design and simulation of a discrete time controller for regulating temperature in a scale greenhouse. *Prospect*, 14(1): 80-88.

[33]Elijah, O., T.A. Rahman, Orrikumhi I., and C. Y. Leow. 2018. An Overview of Internet of Things (IoT) and Data Analytics in Agriculture: Benefits and Challenges. IEEE Internet of things Journal, 2327-4662

[34]Abegunde, V.O.; Sibanda, M.; Obi, A. Mainstreaming Climate-Smart Agriculture in Small-Scale Farming Systems: A Holistic Nonparametric Applicability Assessment in South Africa. *Agriculture* 2020, *10*, 52

[35]Leroux, C.; Jones, H.; Pichon, L.; Guillaume, S.; Lamour, J.; Taylor, J.; Naud, O.; Crestey, T.; Lablee, J.-L.; Tisseyre, B. GeoFIS: An Open Source, Decision-Support Tool for Precision Agriculture Data. *Agriculture* 2018, *8*, 73.