COLOMBIA LAND OF OPPORTUNITIES TO APPLY PRECISION AGRICULTURE: An Overview

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Abstract: - In Colombia, innovation is an aspect of fundamental importance to increase the country's productivity and so it is imperative to promote new ideas, particularly in agriculture sector, where technological developments may lead to the implementation of modern techniques within the production cycle of crops (replacing more traditional, less efficient processes). In this regard, the use of ICT (Information and Communication Technology) and, more specifically, the introduction of IoT (Internet of Things) as a supporting element of the so called Precision Agriculture (PA) is crucial to ensure productivity in crop fields. The present paper shows evidence of a significant productivity increase, based on growth control, achieved by using technological tools that reduce weed volumes around target crops. A set of good practices carried out in specific areas of the world is reported so as to provide an overview of the existing techniques intended to control weeds in different types of fields and under different climate conditions. Subsequently, the paper discusses a survey of the current technological developments in the agricultural sector in Colombia. The discussion ultimately outlines the proper conditions to promote the development of technology-based projects that offer efficient solutions and contribute to the welfare of a specific target population, namely the peasant farmers of Colombia.

Key-Words: - Precision Agriculture, Internet of Things, weed control, climatic change, Information and Communication Technology, fertilizer.

1 Introduction

Climate change and population growth (forecast to reach 10 billion people by 2050) draw worldwide attention to future food supply and also to the implementation of modern (technology-based) agroindustrial processes. In this context, countries whose economies are mostly driven by agriculture (e.g. Colombia) can be pictured as major players in global economies since such countries may provide the world with renewable bio-energy as well as stable food supply. Not surprisingly, the lack of technology-aided agricultural processes in Colombia makes the concept of Precision Agriculture (PA) [1] [2] very appealing to local leaders, and so PA is now perceived as a promising alternative to improve agricultural processes and maximize crop production. Precision Agriculture can be understood as a farming system driven by information gathered from specific technological devices. These devices improve production processes by controlling crop-exogenous variables that guarantee maximum production with minimum environmental impact. To this end, it is also necessary to adjust parameters such as weed control rates, fertilizer use, specific watering patterns, and the proper types of pesticides and herbicides. On the other hand, a society pursuing high quality in their own farming, while minimizing the associated environmental impact (green engineering), should find alternative approaches to weed control, other than only applying herbicides that may cause serious damage, illnesses and even pollute the lands. Here lies an opportunity for the development and implementation of electronic devices, with suitable strategies, that allow early detection of weeds and ultimately lead to a substantial reduction in the use of herbicides. These elements foster a new scenario for the Colombian community to make the efforts and conduct the corresponding activities leading to the consolidation of a sustainability framework that suits worldwide challenges, such as the 70% increase in crop production that has been forecast to cope with future demand. In view of these facts, the Colombian agro-industry has the potential to become one of the top international food suppliers; however, in order to do that, it is necessary first to visualize the changes in global markets so as to properly adjust farming production systems and effectively increase competitiveness and innovation[3]. Innovation is a fundamental aspect of agricultural competitiveness. Although the local government acknowledges the importance of innovation, the Colombian agricultural system is flawed regarding its vision of the market, which results in very little private investment and scarce adaptation of existing knowledge to the current demand, among other inconveniences like deficient capacity and governance. All these limitations restrict the adoption of competitive strategies at a land exploitation level as well as at a corporate level. However, there is a variety of institutions that support and fund research in these area, also defining their own priorities and assessment criteria. Thus, in order to achieve a sustainable agricultural growth and overcome the structural challenges, the Colombian community should seriously promote long-term competitiveness policies [4].

2 Problem Formulation

2.1 The outlook for technology in agriculture worldwide

Without attempting to present a complete picture of the use of technology in farming around the world, it is reasonable to say that there are plenty of technological developments associated to these topics. Some of these developments include the use of unmanned vehicles (so called Drive-by-wire vehicles) that take advantage of Global Positioning Systems (GPS) to receive precise cartographic information from the internet and ultimately achieve significant improvements in farm productivity. Other technological implementations use human-monitored autonomous systems where a pathway function guides the vehicles to follow rows of crops and a human operator aids in turning and changing directions. Autonomous systems are the result of self-sustainable processes that constitute an identifiable need under difficult circumstances, reducing complexity for drivers in the field as well as improving efficiency [5]. The use of such big trucks is also common in weed control processes in corn and soya fields. In particular, studies conducted in nearby provinces around Quebec show how growing crops row-wise, controlling inter-row distances and taking advantage of the pressing of soil caused by big trucks result in substantial reductions of weeds, allowing early control of weed growth [6] [7] [8]. Another element of technological adoption in agriculture can be seen in the use of image processing. Image processing techniques have become a tool that permits proper manipulation of highly sophisticated processes that require the operator’s expertise. Such is the case of the Butterfly Orchid fields, some of the most important flower fields in Taiwan. The seedlings of these flowers propagate using a weave-wise planting method within an aseptic environment. During the planting process, it is necessary to individually transfer the seedlings to new planting containers according to their different stages of growth. This guarantees that the seedlings have a larger space at each stage as well as the corresponding suitable nutrients. However, to date, transfer tasks are still carried out manually in Taiwan. This manual process not only increases the cost of orchid production, but also makes the quality of transfer results dependent on the skills of operators. As a consequence, an opportunity arises to implement an automatic transfer process that improves quality and reduces the cost. This led to the development of a guided grabbing system based on artificial vision intended for seedling transfer. The system basically consisted of a mechanical arm and a binocular stereoscopic-vision image processing algorithm that calculated the 3-D coordinates of the grabbing point. The system accurately finds an suitable grabbing point near the roots of the seedling [9] . Some other relevant work is presented in [10] [11] [12]. The authors show a method for the classification and diagnosis of species of forage crops. This method can classify a variety of grass species in a wide range of tropical regions where forage crops account for almost 90% of ruminant food, particularly in Brazil. Also the method helps to distinguish a species called Brachiaria which occupies 80% of the remaining region. This latter species is the most commercialized species worldwide and so its commercialization brings substantial profits into the Brazilian economy. The classification method consists in identifying, collecting and carefully scanning the species by using artificial vision. The method builds an image data-base, and, based on fractal algorithms, achieves proper classification and identification. The approach of this method allows discriminating the Brachiaria species from digital imagery. Forage crop identification is always achieved together with the necessary information to solve any problem associated to grass quality; this information contributes to improving the quality of food for ruminants, which in turn produces healthier ruminants. This method has achieved high rates of success, which suggests it is a reliable and efficient method.

As illustrated above, image processing represents an efficient alternative in plant identification for crop production. Image processing can identify plagues and unwanted weed in any crop field [13] [14]. However, this type of image sensors may eventually introduce errors caused by the weather wearing out the physical components of the system. This is to say that weather conditions have an impact on the information obtained by sensors i.e. information on the shades of green captured by sensors. For this reason, new ways of acquiring the actual color in images, with no alterations, have been created. These new strategies entail software development based on techniques such as Fuzzy Logics, and Expert Systems, which make use of thresholds in order to distinguish between plants and soil and also between objects of interest and the background. All these strategies meet the conditions associated to perspective, depth and trail as their guidelines. The corresponding methods evolve by applying statistics to their thresholds, which results in a reduction of the weather associated errors. This leads to the creation of various algorithms that reduce any alteration of the variables of interest [15] [16]. This type of errors is caused mainly by the spectral similarity of the green shades to their red counterparts. A histogram-based image analysis is then proposed to select images before classifying their corresponding pigmentation or color shades, thus ruling out the images that introduce inconveniences during the information extraction stage. Subsequently, the elements of an image are classified twofold, green (for plants) and no-green (for all other elements in the image) [17] [18] [19]. As shown so far, Precision Agriculture involves the use of technological developments, either simple or complex, that help to achieve higher productivity from crop fields and soil treatments. In [20] [21], sensor networks were analyzed as a model to predict the behavior of climate-associated variables. The proposed method uses a set of self-development sub-models to capture the dynamics and correlation from the network of sensors placed in the field. Each group represents a set of sensor attributes that are closely related. The model yields a precise prediction from the sensor when the appropriate attributes are selected during model training. However, improvements in crop fields are not only the result of using technological tools, it is also necessary to conduct joint processes based on manual plough, which is the case in some regions of Asia [22] [23]. In these regions, weed represent the main biotic limitation on rice plantations, which causes losses of the grain of up to 100%. This devastating effect is caused by the weed impeding the normal growth of the crops. Various methods to cultivate rice have been implemented to overcome this problem [24] [25]; however, when conducting weed control, several factors need to be considered (e.g. humidity, type of soil, and the weather conditions, among other factors) that may impede the normal growth of the grains. In this context, it becomes necessary to have a look at the way ploughing techniques are applied. The information provided by the aforementioned study should facilitate better decision-making when treating weed by integrating ploughing techniques with other weed control measures over dry-rice plantations [26].

Although it is true that Asian countries have a workforce able to integrate technological tools and farmers, the crop production processes currently carried out in Western-European countries suggest that there is a higher cost associated to manual agriculture. This fact has led the industry to deal with interesting challenges towards developing weed control systems [27] [28], which should be compared with more traditional manual methods. The study presents the development of a mechatronic system intended to remove weed in row-wise planted fields. The system achieves its goal by using rotating hoes, which consists of a set of metal-arm supports that rotate according to the angular position of individual hoes relative to the position of the plants. This guarantees proper weed removal given the irregular space intervals the may exist between plants in the same row as well as between adjacent rows. This is important because, in general, no action that affects the crops should be taken and so an optimal way to handle the hoes must be found, i.e. proper hoe speed and angle must be applied with suitable and sustained synchronization throughout the whole weed-removing process. Once a proper combination of weed-removal strategies was achieved for both typical and unusual situations, the speed synchronization was carried out using knowledge about the plant's position as well as the angular position of the mechanical arm with respect to the end point. Similarly, a virtual prototype was developed to test the effectiveness of the whole system together with the different configurations of for each type of strategy i.e. according to the type of crop and its particular condition. Irregular distances were considered between plants and between row directions. By revising and analyzing each situation, the tools allowed accurate calculations of the impact on the adjacent spaces for all configurations tested. The purpose of these configurations was to optimize both the angular position and the speed. The results also suggest that, by using a proportional control for the angular speed it is possible to achieve a correct adaptation with respect to the irregular positions between rows of the same crop; also achieving an exact collocation of the mechanical arms and their effectors when removing weeds. This observations together with a set of simulation experiments illustrate how the impactrates (crop-damage rates) decrease, both for the crop itself and for adjacent crops. Moreover, this intrarow weed-removal system provides enough flexibility to allow proper adaptation to a range of unexplored problems that are may occur in other types of fields. Since there is no use of chemical substances, these weed-control methods should result in a better quality crops, also reducing the negative impact on the environment when compared to more traditional chemical-based weed-control methods [29] [30] [31]. Meanwhile, the information about the problems associated to agro-chemical methods, which can be provided to consumers and producers, may encourage new trends in the design of systems for weed control, which ultimately should contribute to a quicker acceptance of sophisticated mechatronic-based solutions by the general public. Such is the case of another pair of constructs known as Conservation Agriculture [32] [33] and organic farming, where weed removal is carried out manually by farmers. This more traditional trend is commonly observed in onion fields, where manual weed-removing processes account for almost 90% of the cost associated to weed control. Similarly, another important point of these traditional practices is that the workers involved in such manual processes are exposed to a variety of healththreatening risks. For example, manual weed removal requires workers to constantly adopt bad postures, which causes serious muscle-skeletal illnesses. Considering such human-health aspects, other corobotic systems emerge [34] [35]. This strategy is based on an interaction between men and the so-called corobots, and can be seen as a symbiotic union where the strengths of human beings are maximized by taking advantage of machines to carry out harsh tasks that may represent a health risk for workers (e.g. manual weed removal that entails repetitive harmful movements). Farmers, for their part, will have the skills to visually supervise weed detection and at the same time synchronize the hoe's movement to the shape and direction of the crops by using the co-robot, adjusting the control points of the robot within crop rows in real time. Thus, an alternative method to maintain proper weed control in crop fields is achieved with respect to the cost, which is significantly reduced when implementing this type of methods. By using artificial vision sensors together with human detection skills to locate and remove weeds, a very efficient system emerges, which provides reasonable added values for farmers since it reduces the level of risk for workers in terms of muscular-skeletal lesions and illnesses. This is to say that the design of such robots contributes to improve aspects such as the protection of workers, substantial cost reductions and also production time reductions [36] [37] [38]. Other implementations, carried out in Turkey in 2012 and 2013 illustrate the use of Nitrogen on cotton fields to perform weed control. Experiments were conducted at Kahramanmaras Agricultural Research Institute to observe the effects of various Nitrogen rates. The findings point to a model dependent on four log-logscaled parameters that allow an increase in free-ofweed time intervals in various fields [39] [40]. Another potential weed control strategy lies in biological control [41] [42], that is, the development of a series of illnesses that only affect a specific group of weed and have no harmful effect on crops. As part of a project to refine the prioritization of biologically controlled targets (target weeds) in New Zealand, a set of factors believed to affect the cost of biological weed control were studied. These studies made use of specific information such as taxonomical isolation of the target weeds relative to the native flora and fauna, and also relative to the most relevant commercial pants in the region [43]. The idea is to generate a control system that determines and regulates weed-reproduction rates according to the zone and the particular features of the region where devices are implemented. However, this increases both the cost and the ease of implementation to carry out weed control on different types of fields. To overcome such difficulties, a biological control program was designed to reduce weed and, at the same time, reduce the impact of weed removal around the target area. As mentioned above, this control strategies significantly increase production costs and therefore it is necessary to find a lower-budget system to meet the same goals i.e. reduce weed at minimum cost.

3 Colombian Advances

Colombia is easily identifiable as a country where the agricultural sector plays a major role in the development of current national policies. In fact, to attain the goals of the current national development plan, five cross-national action plans must be followed, namely 1. Strategic infrastructure and competitiveness, 2. Social mobility, 3. Green growth and countryside transformation, 4. Consolidation of the social rights state and 5. Good practices of government. These five strategies, together with a surrounding strategy of green growth, drive the guidelines of the new policies, which are intended to push the country forward towards the construction of a nation in peace, with equity and better education for all. Every single crossnational strategy sets out its corresponding specific aims to attain these three primary objectives [4] [44]. Regarding a rural approach, as stated in the official document entitled “Bases del Plan Nacional de Desarrollo”, the gap between the countryside and urban development is enormous according to social growth indices. Specifically, most of the problems associated with poverty, lack of education and lack of infrastructure are found in the countryside. Additionally, it is important to consider that almost all violence and the production of illegal drugs are concentrated in the Colombian countryside. For this reason, it is necessary to develop an integral strategy intended to transform the countryside. Such a strategy should meet essential needs and modernize most processes, beginning by basic elements like the use of cartographic aids, land registry, property titles and access roads. As this elements begin to appear in the rural context, the concept of green growth can be incorporated since the sustainability of economic growth also depends on environmental aspects and environmental goals are associated to the conservation of and sustainable exploitation of natural resources. In this regard, studies like those presented in [45] show how the nation is moving towards the development of techniques that permit having better quality of grass throughout Colombian fields. The authors carried out observations of pastures and meadows, with kikuyo grass as the predominant species, all over the northern region of Bogota as well as the urban area of Manizalez. The main goal was to determine the areas suffering the highest impact caused by the presence of aphid S. flava. Throughout the rounds, grass foliage was collected to evaluate the damage and take samples of aphids, which were taken to the entomology laboratory at U.D.C.A for further analysis i.e. definition, adult growth and identification of natural enemies. In [46] [47], an evaluation of pastures is carried out using various criteria. This evaluation represents an important tool for decision making when dealing with sustainable systems for cattle. The main purpose of this study was to build a national state index based on productive and biological indices calculated from herbaceous and woody components. The results typified 50 pastures belonging to the same zone of cattle exploitation at “Hacienda García Abajo” in Cauca, Colombia. In Colombia, there is a large number of wetlands, which are considered as important ecosystems due to the natural benefits and services these places provide for communities (e.g. flooding control, fertile soils, pollution control and biological services). However, despite their importance, in Bogota there is a long list of wetlands that have not been treated, not even officially acknowledged, which renders these wetlands vulnerable to potential destruction and disappearance. As a response to this potential danger, in [48], the authors carried out a characterization of the flower composition of a wetland called Chorrillos by using sampling and taxonomic classifications of all species found. The study also provides a comprehensive survey of the species of plants that are typical of wetlands in Bogota so as to compare the species at Chorrillos with previously reported species. This helps to highlight the level of degradation of the wetlands (caused by human actions that are not monitored or controlled by local environmental authorities due to lack of official recognition of the region as a national wetland). The documents also contribute to supporting the foundations of a future project intended to acknowledge these wetlands as official national wetlands and so take legal actions for their protection. The purpose is to prevent further degradation and eventual disappearance of the natural benefits and services provided by these wetlands to the local communities. These environmental issues have also been a central topic in the discussions held by the National Federation of Coffee Producers (Federación Nacional de Cafeteros – Cenicafé[1]) since a wide range of weeds have been found to resist the effects of glyphosate. It was then evident that there is a need to find alternatives to weed chemical control that contribute reduce the selection strain caused by the generalized use of the same herbicide applied using a single course of action [49]. Based on the results obtained in these studies, it was possible to conclude that glufosinate ammonium is an alternative for coffee plantations within a program of integrated weed treatment. The use of this alternative herbicide may contribute to reducing the appearance of glyphosate-resistant weeds. Other studies [50] [51] introduce a combination of GPS devices and selective application of herbicides. The documents show an interesting perspective of these issues by considering the stability of weeds over time. It is known that, in the long run, weed associated flora exhibits transformations in its composition depending on the type of soil treatment and the planting techniques, which represents a crucial fact when drawing a weed map. These facts show how technology-aided processes gradually move forward in Colombian fields, from wetland environmental control and the use of specific herbicides to techniques intended for pastures control. However, a lot of efforts are still remaining. Such is the case of nationwide projects like Safe Ago-Incomes (Agro Ingreso Seguro – AIS[2]), which illustrates the technological gap in the country [52]. As part of the arguments associated to the production boundaries, in this project, policy makers include the factors and input variables that enter the productive process and whose proper use depends on optimal decision making by producers. At the same time, the document includes, as crucial for efficiency levels, a set of variables associated to the productive context (e.g. water availability, quality of soils and yearly rainfall), policy-specific variables (e.g. access to improved genetic materials, access to bank loans, technical assistance and training programs), and variables linked to partnerships (e.g. agreements for commercial distribution of products or coordination between various producers during the initial planting stages). Similarly, the study illustrates that there is only little difference between the groups of products regarding aspects like gender (male or female farmers), quality of soils and rainfall indices. Average conditions are also similar in terms of access to previous loans, water availability, use of genetic materials and previous technical assistance. In this latter categories, access is somewhat restricted (very low percentages) and there is little coordination between producers and vendors when supporting the planting process. Differences are rather significant regarding technical assistance, where the lowest percentages of access are associated to basic products (29%) and the highest percentages are typical of coffee production (49%). In terms of access to training programs, the group of transformable products stands out (39%) while coffee production is surprisingly the sector with the lowest percentage (19%). This latter sector, however, stands out due to its access to basic services for the processing of products (68%). Therefore, the previous results suggest that there is technical inefficiency in coffee production in Colombia. Average producers exhibit relative efficiency rates of about 60% when compared to the most efficient producers, which indicates that there is room for productivity improvements and extensions in this sector with no need for introducing significant technological changes. Two important aspects that are presented in [4] point out some crucial elements necessary for Colombia to achieve international recognition, namely: • The need for more efforts intended to achieve sustainable growth and guarantee that, in the future, international competitiveness is based not only on commodities but also on agriculture, manufacture, and commercial (tradeable) services. • Innovation is a key factor to meet the challenges outlined for Colombia. Complementary contributions to innovation may include strategies such as the development of new economic activities, the promotion of production strategies intended to sustain income and employment rates in growing urban populations, incentives for agricultural diversification that improve subsistence conditions in rural areas, and an increase in environmental sustainability policies to deal with the effects of economic growth.

4 Conclusion

Colombia needs the type of technological developments that can be incorporated into the economy by engineering projects. This actions

1 Science, Technology and Innovation for the Colombian Coffee Community

2 This national program was legally created under law 1133 (2007) with the purpose of improving competitiveness in the agro-industrial sector; also to achieve international recognition for the Colombian economy and to protect the income of producers facing the so called “distortions derived from external markets”.

should prepare the nation to meet socio-economical as well as naturally imposed challenges such as poverty reduction and climate change. It is then essential to articulate innovation and creativity to satisfy real needs like those pertaining to the agricultural sector. Good practices and their corresponding developments have been adopted recently, yet with scarce occurrence and reduced support from the private sector. Then it becomes necessary to promote a mass development of good practices to meet current challenges as well as future challenges. In this context, the guidelines put forward by UNESCO become extremely relevant when pointing out that engineering must be presented as a set of disciplines that are adequate to solve current problems and that satisfy the needs of the society and its development. In the near future, the need to create a significant synergy among engineering, science and technology seems inevitable. These joint efforts must be aimed at developing tools and devices that modernize the Colombian countryside in such a way that, supported by ICT mass-circulation policies, allows a true incorporation of the so called Internet of Things (IoT), and ultimately leads to the creation of added-value chains that contribute to recover the status of life in the countryside. Projects intended to solve small problems regarding aspects like soil preparation processes, plague control and weed management (not for absolute elimination but for healthy weed removal) allow a gradual improvement in the quality of life for farmers. This results in better opportunities for engineering to play a more significant and sensible role within the rural context as a problem-solving discipline. A wide range of challenges arises together with an equally vast spectrum of opportunities to work in the agricultural sector. These opportunities should lead to a promising future for engineering professionals in Colombia and so should promote human, social and economic development. It appears that this is the way the national government has embraced the current situation, since national development plans now promote various types of official invitations for science and technology professionals aiming at implementing technology in the country side. Developments and innovation are expected to thrive towards a better quality of life, which, as pointed out above, are an important part of the national development goals for the new millennium.

4 Acknowledgements

We would like to thank the comments from ing. Edwin Duran (Chief of Research Engineer Faculty of Universidad Católica de Colombia), the comments were helpful in structuring the paper, for his help in literature searches and other details.

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