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Adoption of Artificial Intelligence in Agriculture

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Abstract. Agriculture is facing major challenges. Increasing the total production by 70% in order to suit the world's demand in the next 50 years is an objective endangered by limited resources, climatic changes and other short term and regional threats.

Despite its relatively short life, Artificial Intelligence is seen more and more as a solution to these challenges. The idea that these problems will be surpassed using the technology goes forward, some opinions advocating that humanity will merge with A.I. in the next 50 years, reaching a new phase of evolution. On the other hand, millions of people have no access yet to basic resources, like food, water and shelter.

This study outlines the trends of adoption and the development of artificial intelligent agents in agriculture, focusing on expert systems, sensors for collecting and transmitting data and robots developed for agriculture, in an attempt to reveal their potential impact in this field.

Keywords: artificial intelligence, agriculture, adoption, robots.

INTRODUCTION

Agriculture is facing new major challenges nowadays. The global population is expected to reach more than nine billion by 2050, requiring a growing in agricultural production by 70 % in order to suit the demand. Only about 10 % of this growth may come from availability of unused lands, with the result that the rest of 90% will need to come from intensification of current production (FAO, 2009).

Intensification in agriculture sets a high pressure on energy, mainly represented by fossil fuel, the supply of which is predicted to be insufficient to meet the demand over the next 15-20 years without radical measures and investments in all over the world (Kfm. Jörg Schindler, 2008; International Energy Agency, 2009). The gap between available water supply and water demand is increasing in many parts of the world. By 2025 over three billion people are likely to experience water stress (UNDP, 2006). High rate of consumption in the available resources has also a negative impact on the environment, mainly represented by CO2 emissions and deforestation, both causing global warming. Large areas will need to adapt to new environmental conditions, a process unfeasible in all situations due to scarcity of resources, resulting in further food insecurity, especially for developing countries (Mark W., 2008).More than that, short term but difficult to predict events, like financial crises, human or animal epidemics and price volatility of agricultural inputs and food, amplify the uncertainty about farming activity and raise serious concerns to consumers and authorities (FAO, 2010; Brian Coffey, 2005).

Along with traditional methods of political and economic measures, Artificial Intelligence (A.I.) plays a growing role in the eyes of scientists and governments, in an attempt to face these challenges (U. Cortés, 2000; E. Gelb, 2008). Despite the relatively short history of this field, complex platforms and devices for solving some specific problems have already been developed (National Research Council USA, 1997) and intensive research projects are ongoing.

The idea that these challenges will be surpassed using the technology goes forward, some opinions advocating that intelligent agents will substitute human labour and humanity will merge with A.I. in the next 50 years, reaching a new phase of evolution (Hans Moravec, 1993; Ray Kurzweil, 2006; Mihail C., 2003; James Hughes, 2004).This paper tries to outline the A.I. adoption trends in agriculture, starting from the existing state of affairs and going to the intrigue zone of these futuristic ideas. It would be possible in these new circumstances that the artificial intelligence could be the answer for a few million years old fundamental issue, like scarcity of food?

Other papers (Lawrence R. Jones, 1992; Gelb E.M., 1997; Ning Wang, 2006; Matias Collar, 2009; Ahmed Rafea, 2009; Denis Hollecker 2010; David Gardner, 2010; Scott A. Shearear, 2010) treat to some extent the topic, without necessarily trying to answer the above question, but the subject claims permanent attention and reassessment of opinions, because of the rapid evolution of this field.

MATERIALS AND METHODS

The paper is based mainly on literature review and statistical data. Exploratory trials of 64 software and online expert systems for agriculture were conducted by the author. Around 200 videos with regards the last discoveries in robotics and automation were viewed on Internet.The investigation was conducted referring to three major groups of intelligent agents: expert systems and software designed for farming, special sensors for collecting and transmitting data and finally, robots and automatic systems used in agriculture.

Insufficiency of systematic and reliable data made it impossible to advance consistent figures about the adoption rate for all types of artificial intelligent agents. Instead we generally chose to describe them by categorizing in three groups: intelligent agents already in use, intelligent agents commercially available (for that found in the first stage of diffusion on the market) and intelligent agents in a project stage - for prototypes not available for practical use at farm level.

RESULTS AND DISCUSSIONS

The term *Artificial Intelligence* was introduced in 1956, as “the science and engineering of making intelligent machines" (Andresen, S.L, 2002).

Building intelligent agents (machines) able to find solutions for complex problems and to achieve goals like humans, proved to be a difficult task, despite the initial enthusiasm. This involves reproducing complex behaviours like perception of the environment, reasoning and planning, learning, using natural language (writing and speaking), motion and manipulation, only to name a few (Matthew Stone, 2006).

If considering the “general intelligence” concept, which tries to copy or replace somewhat the human mind entirely the progress is not so spectacular, in some particular narrow areas have been created intelligent agents (Pamela McCorduck, 2004) which perform better than a well qualified person and brought positive economic and environmental results (Ahmed Rafea, 2001; Kees de Koning, 2010).

Some of these applications were developed for agriculture or were adjusted and adopted in farming from other industries.

Expert systems & software. The planning process (either strategic or operational) has benefited substantially, due to the expansion of personal computer and Internet use.

There are in use today numerous expert systems able to solve complex tasks, taking into consideration technical, economic, and environmental factors. The solutions are generated using a structured knowledge base and reasoning mechanisms acquired from humans expert (Ahmed Rafea, 2009) but with an enhanced computational power and speed.

The expert systems are able to demarcate management zones taking in consideration soil proprieties, meteorological data and other relevant factors, they are able to suggest suitable crop rotations, optimal density of crops in the planting stage, water needs and irrigation schedule, fertilizer rates and the proper time for application. Expert systems are also capable of diagnosing pests and diseases for crops and suggesting preventive or curative measures. They can indicate the proper time for harvesting and to specify how to use efficiently farm machinery and personnel (Kiong Siew Wai, 2005).

In the stock raising field, expert systems are able to prescribe feed rations, medications, health and welfare conditions for livestock and can recommend the mating partners for improving genetic potential of offspring. The expert systems are able to perform complex analysis of health, reproduction status of individual or groups of animals, to keep track of production and recommend operational measures to be taken in order to improve the farm performance (VEEPRO, 2010).

Some productive features of animals can be established based on DNA samples in a couple of days, reducing the time and cost of estimating them with experimental methods. Advancement of computerized systems, made possible the sex predetermination of offspring using sexed semen, a technique available on a large scale for cattle and horses and applied with limitations for sheep, goats and pigs. (J. M. Morrell, 2011). From another perspective, the expert systems able to process information and to deliver complex reports, helped farmers to comply with the administrative requirements and interact better with authorities.

Although there are over a few hundreds of autonomously expert systems able to trade online on specialised markets (Violeta Gaucan, 2010) we couldn't identify expert systems or software for trading agricultural products, excepting common websites for advertising and selling products and inputs. The decision making process at group level is also uncovered by special software for farmers, although some popular applications (Messenger, Facebook) are broadly used worldwide for socialising.

The scientific literature and exploratory trials conducted on available software illustrates that expert systems cover almost all relevant areas of interest in farming activity but their number and complexity varies from country to country. A total number of 1315 software has been reported in eight European countries since 1996 (Gelb E.M., 1997). But if more than 105 software for livestock farms are registered currently in France (Jean-Marc Gautier, 2010) I could identify only one in Romania, none in Bulgaria, all three countries being part of European Union.

Underdevelopment of IT infrastructure in many regions is certainly the first obstruction in using the new technology, only 30.2% of the world population having access to Internet. The penetration rate is still low in Africa (11.4%) and Asia (23.8%) in contrast with 71% in developed countries (World Internet Usage and Population Statistics, 2011).Lack of knowledge in the use of computers and linguistic barriers are also two important causes of not using them on a large scale. Some of the expert systems are designed to cover a specific agricultural region, so only a restrained group of farmers can use them.

Alongside the common causes of expert systems penetration to farm level, there are also specific problems related to this adoption process. Except indoor environments (greenhouses, pig and bird shelters), where integrated expert systems with a high degree of independence in making operational decisions are already commercially available, the expert systems are generally still disconnected from background and from previous experience when delivering solutions and also are highly dependent by integrity of data supplied by the operator (ICT-AGRI, 2010). Other important barriers in using expert systems are also the amount of time and effort required to collect and input the required data and their relative rigidity caused by structured knowledge databases.

A survey conducted in the USA (National Agricultural Statistics Service, 2009), revealed that in 2005, from approximately 51% of farmers owning a computer and being connected to Internet, only 33% were using the computer for farm business. At the same time, only 5.3 % of dairy farmers were using computerized milking systems and 7.1% were using computerized feeding systems (Jeffrey Gillespie, 2009).Another survey conducted in 2007 in Ireland showed that 56% of farmers owned a computer, 35.8% of farmers used the computer for farming matters, while 15.2% were using a farm management software (Padraig Wims 2007).Major improvements were made in the last 20 years in designing friendly and accessible interfaces and as a result, the expert systems are available to each person able to read and to use a keyboard and not only to the scientists as in the first stages of development. Text, images, sound files and videos are the common tools of human-computer interaction.

Although we couldn't identify commercially available expert systems for agriculture that can be used via natural speaking language commands, this technology acquired a considerable attention over time (Lawrence R. Jones, 1992) and the advancement of technology is notable, making this option possible. There are already commercially available software capable of speech recognition, speech to text transcription, software for controlling computers with voice and software able to perform instant translations from a source language to another language (Verma Awaneesh, 2011), so integrating them in expert systems is only a matter of time.

A remarkable achievement in this field was recorded recently (February 2011), when an artificial intelligence computer system developed by IBM, defeated in a quiz contest the two best human players in the whole history of the game. The experiment proved the high ability of the machine to interpret metaphoric or allusive questions posed in natural language, and to give answers in a natural speaking language, quicker than human counterparts. According to IBM officials, the company is already working to implement this technology in the healthcare, finance and telecom industries (Armonk N.Y., 2011) and over time this technology will become available also in agriculture.

More advanced technologies like human-computer interaction via brain signals are in the early stage of development in health and entertainment industries mainly. Non invasive applications, which allow operators to interact with the software focusing or thinking to some symbols or objects, were released in the last five years on the market (Darren Waters, 2008; Rick Dakan, 2010). The accuracy and efficiency of these systems doesn't allow them yet to be incorporated into a viable expert system for agriculture, but projects to develop these technologies are part of the current research strategy (Mihail C. Roco, 2003).

A quantitative analysis of the Internet adoption process shows us that the penetration rate increased worldwide in the last ten years, with 15% of the world population being connected at every five years. In Iceland, Norway and Sweden 92% of the population is connected to Internet. It is expected that more than 95% of people from Europe and USA will actively use the Internet in the next 6-15 years and 75% of people will do the same worldwide by 2030 (TNS Infratest, 2009).

Qualitative aspects, like technology advancements, decreasing the adoption costs, early education for using the computer, new administrative and legislative requirements, are strong arguments suggesting that adoption of expert systems and specialised software will follow the same trend, becoming usual tools for quasi most farmers, before 2040.

Sensors for collecting and transmitting data. Improving the interaction human-computer doesn't guarantee the validity of the solution generated by the expert systems. Human operators can accidentally alter the data fed into expert systems, applying improper techniques to collect them, due to the subjective appreciations or making errors in the inputting process. Delivering data continuously or frequently is not a feasible option for a human operator. Special sensors designed to collect and transmit data to the expert systems are more precise and cut down the necessary effort and time for these operations.A range of special sensors are commonly used today in agriculture especially embedded in complex agricultural machines or placed in farm buildings or in their proximity.

Widespread sensors are used to measure and transmit data regarding air temperature, air humidity, atmospheric pressure, soil temperature, soil moisture, soil pH, solar radiation, wind speed, wind direction, rainfall and leaf wetness (Ning Wang, 2006). There are also in use many sensors for collecting and transmitting data related to farm machinery (location, technical functions, productivity, fuel consumptions etc.) and about rate application of seeds, fertilizer, water, pesticides, and forages. There are also commercially available sensors able to measure continuously the growth and size of plants, fruits or animals and to test quality of products after harvest (ICT International, 2009).

The use of electronic identification tags for some farm animals is mandatory in Europe and is widespread also in some other parts of the world. Prototype collars able to restrict animal access to a predefined area using the computer were tested. There are also in use sensors for collecting biologic data from animals (heart rate, temperature, movements) and precisely locate every animal, via satellites. However, the use of sensors outdoors still has important limitations, mainly because of their low energy autonomy, short distance data transmission capacity and lack of integration.

Research projects are ongoing to develop sensors capable of accomplishing new functions, like detecting pre-symptomatic disease in plant and livestock production, measuring infestation levels, discriminating species and individuals from backgrounds. As of a more technical perspective, the efforts are directed towards developing cheaper wireless sensors, able to collect and transmit data when sensors are in motion, to increase their autonomy, and to integrate them in networks able to manage complex and continuous received data (ICT-AGRI, 2010). Measuring the actual penetration rate of the sensors is a difficult task because they are used both embedded in agricultural machines or robots, but also could be found as independent agricultural tools.

*Robotic and automation.*Making right decisions in agricultural activities is less than half the way needed to achieve desired results. The intelligent agents (robots and automatic devices) implementing measures into practice are seen more often as a feasible solution for the future, for increasing technical and economic efficiency and reducing the environmental negative impact of farming (Thomas Bak, 2004).

Manipulator robots have been used with great success in factories in the last 50 years, replacing human workforce in repetitive and tiresome tasks. There were nearly a million robots in operation worldwide. Half of the robot population is located in Asia, one third in Europe, and 16% in North America. Australasia and Africa each account for 1% (IFR, 2007).

But the robots couldn't be adopted on a large scale in farming, where the environment is unpredictable and ever-changing and many repetitive tasks are not exactly the same every time. Nevertheless, starting with 1970, emphasis was towards developing mobile robots and humanoid robots, able to deal with unstructured environments (Rodney Brooks, 2009), which opens new perspectives in this direction, robots being credited with a considerable impact on future farming (David Gardner, 2010).

Immobile robots and automatic devices are already efficiently used for some indoor farm activities, being capable of identifying animals and feeding them according to their nutritional needs and expected production, weighing and separate them, selectively milking the cows, sheep shearing, clean up the shelters, slaughtering animals (Matias Collar, 2009).
In some green houses, the temperature, humidity, light control, fertilization and phytosanitary treatments are automatically completed. For some crops there are commercially available fully autonomous robots dealing with the whole cultivation process, from planting to packaging in a greenhouse (Daniel de Nokker, 2004).

Important progress can be noticed also regarding outdoor activities, both in establishment crops, plant care and selective harvesting. There are already commercially available autonomous mobile robots capable to selectively harvest almost all kind of fruits (strawberry, pears, grapes, water melons) legumes and flowers (Scott A., 2010).

Automatic guidance systems which can be installed on conventional tractors are already in use, reducing considerably the effort of the drivers and being credited also with improvement of technical and economic efficiency (Dave Franzen, 2009). A robotic driverless tractor, capable of following a predefined route and to react to unknown obstacles was developed and successfully tested, but it can not be used unattended in fields at this point, especially for safety reasons (Scott A., 2010).

At the 7th Field Robot Event organised in July 2009 in the Netherlands, eight prototype field robots with autonomous navigation system and weed destruction integrated functions were tested in a natural environment (Wageningen University, 2009) with promising results.In other industries more complex robots have been developed, which could have an important impact on agriculture in the near future, but a few are commercially available.

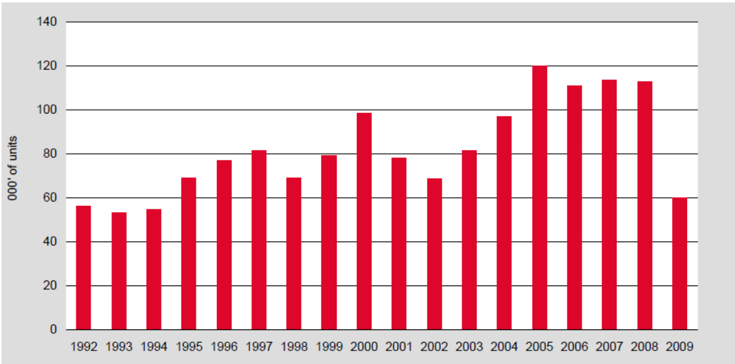
For example ASIMO, credited as the most advanced humanoid robot ever built, can naturally walk in an unknown environment avoiding obstacles, can run with speeds as high as 3.2 km/h, and can comprehend and carry out simple tasks based on simple voice commands given in English. ASIMO conducted the Detroit Symphony Orchestra in 2008, successfully replacing the bandmaster. Other humanoid robots are able to walk, run, dance, cycle, play some sports, compose music, sing, play to an instrument and respond to tactile, audio or verbal stimuli.

In the latest competition organised by USA Defence Advanced Research Projects Agency in 2007, six fully autonomous cars finished a 96 km race in an urban environment, the vehicles being in a situation to make intelligent decisions in real time based on the actions of other vehicles or obstacles and to obey all traffic laws, without having a driver.Despite these technological achievements, the diffusion rate of automatic devices and robots for agriculture is still in infancy worldwide and considerable dissimilarities can be noticed from country to country. Another discrepancy can be noticed between indoor activities and outdoors ones, due to available technologies.

Milking robots, introduced on the market in 1992, are the only representative class of robots used widely in farming and occupy the second position (after military robots) in service robots class, with a share of 25%. The number of installed milking robots increased from 6,180 to 22,980 units (272%) in a three year period, between 2006 to 2009 (European Robotics Research Network, 2008, 2010) and is estimated that around 20% of new milking installations in the UK are now milking robots (Dunn, 2009).

Another investigation carried out in 2010 in USA, revealed that the penetration rate of some intelligent systems was between 27.4% (satellite positioning systems), and 9% (map-based field scouting for crop diseases), but these agents are not considered robots (Florian Diekmann, Marvin T. Batte, 2010). Other types of agricultural robots are not counted in relevant statistics, their adoption being in the incipient phase.

The adoption rate of robots in economy (figure 1) seems rather correlated with the economic evolution (grow and stagnation) and not in line with the discovery and innovation rate. The high cost of the robots is a restrictive factor of their adoption,



Source: European Robotics Research Network
Fig.1.Estimated worldwide annual shipments of industrial robots

Projections for the period 2011-2013 anticipate that robot shipments will increase, by about 9% per year on average in the Americas, about 12% in Asia -Australia and by 8% in Europe (European Robotics Research Network, 2010). Fallowing this trend, we can estimate that for commercially available technologies the penetration rate of robots will be 15% by 2030 and a 75% by 2045. In this scenario some activities could be completed worldwide almost exclusively by robots before 2050.

However this quantitative approach is risky. Mechanisation, started as a process 100 years ago, has not showed its potential in some geographic areas. Only around 35% of land was cultivated using tractors in 1999 and FAO estimate an increase barely to 55% by 2030. The cause can only be identified as the unequal access to resources, situation which is not expected to change in the same cadence with the rate of discoveries in science and technology. Considering this argument, we could assist to a slow and uneven adoption process of robots in agriculture, without revolutionary economic and social results in the next 50 years at a global scale, with a completion cycle longer than one century.Even if we accept the first scenario and the replacement of humans with robots in the production process is in a shorter period of time, it is still questionable if this movement will increase the world production beyond some natural limits of land and more than that, there are no guarantees that the distribution of the resulted production will be equitably distributed.

CONCLUSIONS

This investigation demonstrates that there is an unquestionable growing tendency in the adoption of artificial intelligence in agriculture. Computerized expert systems cover a broad area of farming but their number and complexity vary considerably from country to country. Underdevelopment of the IT infrastructure in many countries is the first obstruction in using them, only around 30% of the world population currently having access to these new technologies.

Great progress was made lately in designing accessible applications, shortening the time and effort of operators, but the expert systems are highly dependent by integrity of data supplied by humans and are not yet designed to cover entirely the farm management process. Expansion of the IT infrastructure, technological advancement and positive attitude about the adoption process, support the idea of further increases, with around 75% of worldwide farmers using them by 2030.A broad range of special sensors for agriculture are commonly used today, embedded in complex agricultural machines or placed in farm buildings or in their proximity. They can provide data continuously or frequently, in real time manner, avoiding human errors and improving the decision making process. However, low energy autonomy, short distance data transmission capacity and lack of integration in complex decision systems are important limitations to use them with maximum effect in farming.

The use of robots and autonomous devices in farming is still in infancy. Only in greenhouses and dairy farms the activity of robots can be counted as relevant, but for other activities the robots have just become commercially available or are in a prototype phase, their visibility and outcome in world agriculture being almost negligible. The new technologies in robotic and automation field still require time and investments in order to make them exceed the performance of technology in use today.

The speed and the amplitude of the adoption trend are not easy to predict. The world's socio-economic system is not expected to change at the same pace with the technical advancement in science and communication, keeping unaltered the unequal access to resources. The full adoption of robots in agriculture could take one or two centuries, without producing the expected explosion of global agricultural production in the next 50 years. These conclusions however have their roots in the paradigm of actual agricultural system and human nature, without taking into consideration big transformations of factors, like human metabolism, genetics or energy absorption, scientific achievable, which could supply surprising answers to the problem.

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