Robotics for advanced Human Machine symbiosis in agriculture

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Abstract—Human Robot Symbiosis is like Human Robot Interaction (HRI) in the sense that it is about how humans and robots interact with each other. In such an interaction between robots and humans, they both gain benefits from their collaboration. HRI applications and approaches focused on bringing much needed improvement to agricultural processes are surveyed in this paper. Specifically, focus has been put on applications and approaches that bring betterment in profitability, working conditions, productivity, efficiency and safety of agricultural processes.

Keywords—Human-robot interaction, co-robots, Agricultural applications

1. Introduction

One in nine humans around the globe do not have access to enough nutrients for consumption in order to lead a healthy and active lifestyle (Marx, 2015). Furthermore, the world population is projected to increase rapidly over the coming decades. By the year 2050, there will be a 34% more population increase than at present, where most of this increase will be in countries of the developing category. To sufficiently cater to the nutrient needs of this larger population, food production must increase accordingly by a staggering 70% (FAO, 2009). The increase in the migration of the agricultural labour workforce to other productive sectors has been one of the main contributing factors to the current declination of crop production rates in several countries (Donoso, 2016). This transfer of labour force affects the rural development and agricultural processes negatively. Precision agriculture (PA) alongside being a livelihood provider, it is also one of the key things involved in the fight against hunger and poverty (Sud et al., 2015). Many studies have indicated that investing in agricultural research and development will directly result in solutions that will aid in significantly reducing world poverty and hunger (FAO, 2009). The solutions include technological options that help achieve better sustainability and productivity for agricultural practises. The main topic of study in this work is human robot interaction approaches and strategies to face agricultural production process problems, this paper focuses the analysis on economic aspects such as management, profitability and productivity. The focus of the analysis will be on health and safety aspects as well.

This paper is organised in the following manner: Section 2 briefly describes the concept of human robot symbiosis and its link with human robot interaction; In section 3 a technology review of agricultural robotics is presented; Section 4 is about agricultural applications and HRI approaches therein; 5, presents HRI in agriculture from a health and safety perspective; In section 6 an analysis on HRI agricultural strategies is given from the perspective of profitability, productivity and management; In Section 7 the most relevant works regarding HRI in agriculture are classified; The presentation of conclusions is in section 8.

2. Human robot symbiosis and HRI

Human Robot Symbiosis is like Human Robot Interaction in the sense that it is about how humans and computer interact with each other. HRI is a relatively new and growing field of research focused on understanding, evaluating and designing interactions between man and robot. Specifically, where the robots share physical space and/or can communicate with the humans (Billard, & Burke, 2010). In the Agricultural context, HRI strategies are utilised to enhance the execution of agricultural tasks and all such strategies necessitate a strong Human-Robot symbiosis. In such an interaction between robots and humans, they both achieve benefits from their collaboration.

3. Robots for carrying out agricultural tasks

Agricultural purposed robots (robots purposed for performing agricultural tasks) are systems - typically autonomous or semi-autonomous – used to solve demanding problems (Yaghoubi et al., 2013). Such robotics have become an indispensable tool in increasing productivity and reducing workload of agricultural processes. The reason for this is that robots are successfully utilised in green house applications and many agricultural tasks (Moorehead, Wellington, Paulino, & Reid, 22010). Rapid changes are currently occurring in the field of robotics – the field is evolving and advancing with the passage of time (Boesl & Liepert, 2016). Advancements in algorithms, A.I, computer vision along with growing development in sensors, reduction in equipment costs (due to mass production) and more are the reasons for the rapid evolvement of the use of robotics in agriculture (Hashim, Adebayo, Abdan, & Hanafi, 2018). However, robots currently have the inability to perform complete autonomous agricultural processes and still have a very long way to advance before achieving such a level as it will require substantial investment since most agricultural processes are very complex (Sistler, 1987). To date, the vast majority of robots working on agricultural matters are prototypes and only a few are used commercially (Bergerman et al., 2016). Agricultural purposed robots are operated in various stages of agricultural processes and are used for repetitive agricultural tasks. The aim is to reduce farmer's workloads by optimising costs and agricultural process times such as harvesting, mapping, water irrigation, land preparation, spraying, pruning, monitoring and inspection (Bac, Henten, Hemming, & Edan, 2014). Furthermore, robots have applications in greenhouses where tasks typically consist of transplanting, harvesting, weeding, cutting, grafting, irrigation, precision spraying, crop and fruit harvesting including detection and colour classification (Vitzrabin & Edan, 2016).

In recent years agricultural applications of drones have been a focus of development. Depending on the level of automation, drones fall into one of the following system classifications: swarm drones, autonomous or semi-autonomous (Conesa-Munoz, Valente, del Cerro, Barrientos, & Ribeiro, 2016; Krishna, 2016). Applications of drones for agricultural purposes include taking multi-spectral or thermal imagery of crops, weeds and terrain – essentially purposed for mapping events and natural resources in two and three-dimensions. Such imagery and data obtained by drones are utilized to map crops and soil; analyse moisture and soil type; prevent and detect water deficiencies; measure spray fertiliser, pesticides and weather parameters; detect nitrogen deficiency (Krishna, 2016). The next generation of collaborative robots (co-robots) – which are robots that have the ability to collaborate with humans in a variety of applications such as co-defenders and co-explores (National Science Foundation, 2017) - has been a focus of research in recent times. For this reason, I believe that co-robots facilitate a human-machine (human-robot to be exact) symbiosis by becoming useful dependable assistants and companions for humans in their day to day activities and are expected in the future to be commonly found with people in places such as hospitals, schools and farms. The co-robot concept is a motive of the analyses in the subsequent sections

4. HRI in agriculture

Autonomous robots that are able to work on large scale fields alongside machines which are human operated perform the most agricultural processes currently. Automation based agricultural processes on small and medium scaled fields is difficult and development in this direction appears to be slow. HRI agricultural based strategies delivers solutions to complex problems such as providing benefits like the following to farmers: lower work-load, improved process productivity, comfort and security. Specifically, benefits are packed in agricultural applications such as grasping, detaching, transporting procedures and detection of vegetables and fruit (Bechar & Vigneault, 2016). HRI techniques must be developed to take advantage of both the robot and human skills to facilitate effective cooperation and it must be designed to allow the robot to learn or/and adapt to new (working) conditions (Van Henten et al., 2013) the reason for this is that in agricultural HRI applications modelling each crop, mission and climate is extremely difficult and a sustainable solution to this problem is modelling the systems or approaches that are based on the interaction among agents that can be tailored for each activity to its process and environment needs.

The following are some of the most notable developments in HRI. In (Adamides, 2016) the evaluation of various UI modes for HRI target identification and spray tasks is investigated. This work provides an interface for the teleoperation, where possible, of a targeted pesticide spraying robot. The gui – operated by a human - will guide a robot navigating the vineyard rows. The suggested degree of autonomy is a semiautomatic teleoperation, which means that the robot can operate manually and autonomously which has the added benefit of there being no human exposure to pesticides which is advantageous to the health of man. For this system there are three different interface control options for the purpose of target selection on screen through the UI by the human operator: using a Wii-mote (a type of gamepad), mouse and a digital pen. In (Adamides et al., 2014) agricultural robot operator situational perception is evaluated. It consists of two components: agricultural-robot-farmer and farmer-agricultural-robot. Farmer-agricultural-robot has to do with the farmer's understanding of the agricultural bot's circumstances such as location, surroundings, activities and status. The former - agricultural-robot-farmer - is linked to the robot's awareness – knowledge it has of the human operators' circumstances such as the human operator's behaviour, current status and relevant limits. Moreover, agricultural-robot-farmer has the ability to determine which possible actions are to be taken if the human operator needs assistance. Increasing the environmental awareness of agricultural vehicles that are working in fields is the purpose of a multi-sensory perception system, which is presented in the paper (Reina et al., 2016). Various types of sensor technologies are analysed in the paper– these sensors when used together have the ability to identify obstacles and determine traversable zones through estimation.

5. HRI and safety

The most important considerations in the agricultural industry are Health and safety, since the possibility of accidents are constantly present in many agricultural processes. This is mainly where an individual works by handling or working hazardously close to machinery and hence risk their own physical safety. The introduction of HRI strategies can bring improvement to health and safety in various agricultural processes. Studying situations that threaten the health and safety of humans is needed to prevent accidents (Vasic & Billard, 2013). Taking into consideration the fact that robots can contribute to accidents is vital as they have the potential to perform manoeuvres that can threaten the health and safety of humans. In (ISO, 2011) established requirements to manage safety for co-robots such as ISO 10218 are presented, moreover it presents strategies to increase safety in cooperative human and robot applications such as: an emergency stop-button, purposed sensors (e.g. proximity sensors, force-torque sensors, tactile and pressure sensor), speed and force limits set on robot, nearby humans detecting cameras and area detectors (ISO, 2011). These safety steps cannot be entirely be applied to robotics based agricultural applications nor are they relevant to dynamic/flexible robotic environments. The agricultural field is notorious for having the least safe jobs and it is ranked in many countries as one of the top dangerous fields due to the amount of accidents involving workers (Robert, Elisabeth, & Josef, 2015). Fig. 1 is showing a summary of the most frequent ways accidents occur in a agricultural context, according to this the most common way of an accident is machine collision. Fig. 2 is showing a summary of the most common causes of accidents in the agricultural field, it shows that the most common cause is linked to human factors. From the figures it is clear that in cases where humans and robots share space then it is vital that the robots are designed with safety of the humans in mind (Cheein et al., 2015). HRI strategies can aid in reducing accidents in agricultural environments, especially from the aspect of cognitive ergonomics as robots will be able to perceive human aspects such as fatigue, stress and focus and utilise this information accordingly (Bouargane & Cherkaoui, 2015).

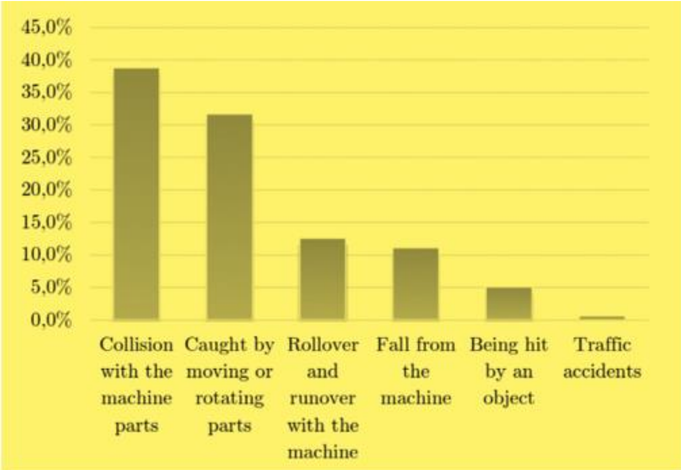

Fig. 1 – Most common accident causes using machinery in agricultural environments (Robert et al., 2015).

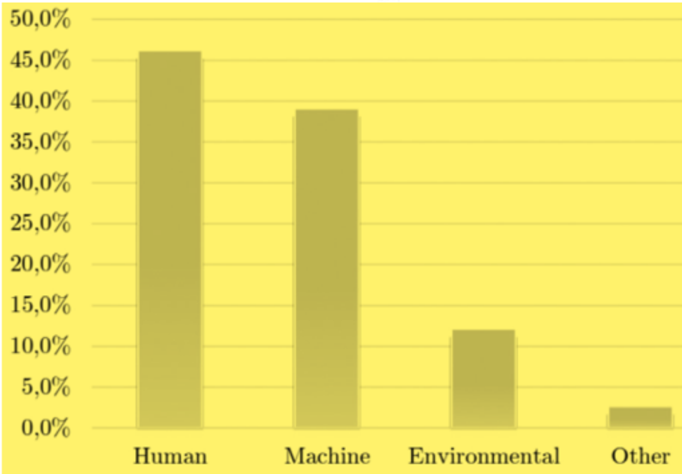

Fig. 2 – Accident causes in agricultural environments (Robert et al., 2015).

6. HRI applications and their profitability, productivity and management.

The most important aim for obtaining agriculture produce sustainably is to make food affordable and accessible to all sundry along with increasing production and to make the entire processes more environmentally friendly, the reason for this is, that in many countries there is an urgent need for sustainably obtained agriculture produce (Garnett et al., 2013). To reduce heavy loads, reduce operational times and enhance productivity robotics have been used for agricultural applications, and the technology is based on reliable studies to ensure successful implementation. Feasibility studies for an economic purpose have shown that autonomous machines are more economically feasible compared to conventional systems for agricultural applications (Pedersen, Fountas, Have, & Blackmore, 2006), some of the reasons for this are that autonomous machines perform jobs more efficiently and are able to work more hours. Autonomous robotic tractors, compared to typical human ridden tractors, have shown the capability of reducing human labour by five times in several agricultural tasks (Pedersen, Fountas, & Blackmore, 2008). A critical disadvantage of autonomous machines in agricultural applications is that their operation and upkeeping might require specific difficult to obtain expertise and complex infrastructure as autonomous machines have shown to only perform repetitive tasks well with external disturbances minimised (Belforte et al., 2007). Autonomous machines carry out agricultural repetitive processes well in large sized farms, but in small and medium sized farms, because of environmental or economical constrains, autonomous machines are not viable (Pedersen, Fountas, & Blackmore, 2008), moreover, certain agricultural processes are too complex to be automated completely, in such cases – where autonomous machines are limited – an HRI approach might be a feasible substitute to carry out the agricultural process. HRI strategies include both a robot and human, the latter is an advantage as it provides additional benefits like the human ability to utilize creativity to solve problems. For an HRI approach to be a valid solution it needs to provide the following over a manual (completely human labour based) or autonomous solution: better quality, increased productivity and reduced costs. As an example, certain robots have been tested to harvest fruit from trees, they have shown to be slow and in need of technological improvement in their sensors and algorithms, an HRI approach is a potential feasible substitute in this case (Aloisio, Kumar Mishra, & English, 2012). A solution based on HRI strategies will have adaptability and flexibility which will also facilitate it to be implemented for agricultural tasks that are season based, where investing in autonomous systems are uneconomical.

7. Discussion

The main features of current HRI agricultural applications are discussed in this section. Table 1 summarises the HRI-related themes of research papers published in the last decade. Moreover, these are compared on the basis of aspects that are the foundations of every HRI, namely, general concepts, metrics, design concepts, taxonomy, and human factors. In the topic of HRI architecture there are a wide range of concepts, applications involved and taxonomy, this is the reason why a comparison of the research papers – that are based on various HRI architecture – is being presented without proper metrics. Furthermore, agricultural tasks such as harvesting, spraying, transportation, and mowing are covered in these research papers.

8. Conclusion

HRI in agricultural applications has been surveyed in this paper. HRI strategies can make up for the lack of labour workforce problem in the agricultural sector by facilitating heavy-work and increasing productivity in agricultural tasks. Furthermore, HRI strategies can enhance health and safety in agriculture by reducing the occurrence of potential accident causes. Many HRI strategies are currently implemented in agricultural environments, however, full advantage of the capabilities of HRI strategies has not been taken yet and the path to achieving this seems long. An analysis of an ISO standard for cooperative applications had been presented, briefly stating that the standard cannot be holistically be applied in HRI-agricultural-tasks. Unfortunately, no standards for dynamic interaction in agricultural tasks exists, for future work this can pose a challenge.

Table. 1 – Summary of HRI in agriculture.

	General concepts					Metrics						Design concepts					Taxonomy										Human factors			
Author	Interface designs	Collaboration models and schemes	HRI concepts	Health and safety	Productivity, profitability and management	Mission effectiveness	Human behaviour efficiency	Human cognitive indicators	Human physiological indicators	Robot behaviour efficiency	Collaborative Metrics	Level of autonomy (LOA)	Nature of information exchange	Structure of team	Adaptation	Task Shaping	Task type	Task criticality	Robot morphology	Ratio of people to robots	Composition of robot teams	Level of shared interaction	Interaction roles	Type of human-robot physical proximity	Decision support	Time-space taxonomy	Human workload	Situation awareness	Trust automation	Mental models
Adamides et al. (2014)	X			X		X	X			X	X		X				S							T	X			X		
Adamides, Christou, Katsanos, Xenos, and Hadzilacos (2015)	X					X	X			X	X		X			X	S							T	X		X	X		
Adamides (2016)	X		X	X		X	X			X	X	X	X				S		X					T			X	X		
Berenstein and Edan (2017)	X					X	X			X	X						S		X					T						
Adamides et al. (2017b)	X					X	X			X	X						S							T				X		
Adamides et al. (2017a)	X						X			X	X	X					S		X					T				X		
Bergerman et al. (2015)	X			X								X		X		X	H		X			X	X	W			X	X		
Freitas et al. (2012)	X				X							X		X		X	H		X			X	X	W			X	X		
Oren (2008)		X				X	X			X	X	X					D							T						
Tkach et al. (2011)		X				X	X			X	X	X					D							T						
Berenstein and Edan (2012)		X	X		X	X	X			X	X	X					S							T			X	X		
Szczepaniak et al. (2014)		X		X			X	X			X						N							W						
Cheein et al. (2015)			X	X	X											X	N						X	W				X		
Reina et al. (2016)				X													N	X						W				X		
Gomez-Gil et al. (2011)	X					X	X	X	X								N							W						
Cullen et al. (2012)			X	X	X								X				M							W						
Bechar and Vigneault (2016)			X	X								X				X	N		X					W			X	X		

X = related information, T = Teleoperation, W = Sharing workspace, S = Spraying, H = harvesting, D = Detection, N = navigation and transport, M = Mowing.

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