Robotics for work and environment safety in greenhouse

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Abstract

Robotics and automation are now widely diffused in most industrial sectors with consequent benefits both in terms of productivity and quality of products and regarding work quality and safety. Robotic systems are not yet diffused in agriculture even in those contexts in which automation is already presented, such as greenhouses. Most operations on crops, in fact, are still usually performed by human operators, often exposed to polluting substances. The introduction of fully automatic machines in agriculture would significantly improve the safety of the working environments and would allow the introduction of new low environmental impact techniques. Precise application of chemicals and herbicides would considerably reduce their use as well as a mechanical weed control.

Different motivations, connected to the particular characteristics of the agricultural context, have strongly set back the development of robotics in this sector so far.

The reasons that prevented the diffusion of robotic solutions in agriculture are discussed in this work, together a number of guidelines that, in the authors opinion, should be followed to design really usefully robot for agriculture applications. Two different multi-purpose robotic cells prototypes, designed and implemented according to such features, are then presented. First of them was conceived to operate in fixed position along a benches displacement line, while the second was a Cartesian tool handler which can be installed in different configurations for its movement within a greenhouse. Both robotic cells were able to perform different operations on pot crops by means simple tools implemented during the research activity.

Keywords: automation, robotics, greenhouses.

Introduction

The latest results of technology and research in advanced mechanics and automation are increasingly used in agriculture, especially in highly specialized intensive plantations that ensure remunerative returns. This is the typical case of most part of crops in greenhouses, at least in the western countries. Although there is a large use of technology, human operators still manually perform most operations on the plants despite the fact that they can be highly repetitive and dangerous. This fact greatly impacts not only the quality of the product and the production costs but also other issues like environmental pollution and operators safety.

The use of robots could significantly contribute to increase overall performances in intensive culture management and production efficiency, reducing costs, and, not least, to improve labour quality and safety. Robots, in fact, can easily perform repetitive task, can undertake operations that are not possible with human operators since their cost in terms of time and/or required concentration is too high. Operations like precise fertilization and spraying of each single plant, precise mechanical weed control can be routinely performed with a robot that can also performs control tasks such as inspection and growth evaluation of each single plant. Meanwhile a robot can operate in an hazardous environment strongly reducing the exposition of human operators to dangerous chemicals. Precise application of pesticides, moreover, could significantly reduce the quantity of pollutants in the environment.

Although robotic and automated solutions have a large diffusion in most industrial sectors, agriculture only marginally benefited so far from automated solutions. Many researches in the sector of robotic applied to the agriculture were carried out in the recent past, but only in very few cases developed solution passed the prototype stage. The reasons for such marginal development of automation and robotic solutions in agriculture are related to some particularities of the operative environment and the specific production context (Kassler, 2001). Agricultural environment is indeed less friendly for robots than the well structured industrial environments: is not possible to have fixed position references; the object, with which machines have to interact, have irregular size, location and shape; operating environment is quite hostile (humidity, dirty, etc). The available solutions are insufficiently robust and costly, they have limited working capabilities, while in general the available knowledge is insufficient to create robots as dexterous and skilful as trained workers.

On top of this, currently available machines usually are able to perform one single agricultural task and therefore can be used only few times per year in connection with the seasonality of agricultural production. This indeed increases the time for investment return and discourages their use. Also at research level only few examples of multi-functional robots can be found (Van Henten *el al*, 2003; Van Henten *el al*, 2007).

A consistent share of the research effort conducted so far mainly tried to use standard industrial robotic solutions adapting them to the intensive farming sector instead of developing brand new solutions that fit the specific features of the agricultural sector.

The aim of this paper is to face the problem of the introduction and diffusion of robotics in the agricultural context following a different approach, in order to allow the introduction of robotics potential benefits in agriculture already in the next future.

Design guidelines

Analyzing with care peculiarities of the agricultural production sector as well as reasons that have prevented the diffusion of robotics in this sector so far, it is noticeable that robotic solutions employed in industries are not suitable for agricultural applications. For this reason it is necessary to develop innovative machines really usefully and that meet farmer requirements. To do so the following guidelines should be considered.

Robot accuracy

In agriculture errors and uncertainties of some millimeters are usually acceptable. This implies that robots suited for this kind of application can have errors and uncertainties about 2-3 order of magnitude greater than those required in robots designed for industrial applications. It is important to take advantage of this fact designing specific robots that can be much lighter since stiffness of the structure is not a main issue and components need not to be very precise.

Robustness and simplicity

The greenhouse environment which is humid and dirty with possible spraying of chemicals suggests simple and robust mechanical solutions based on standard components, easy to maintain. All this ends up in considerable costs reduction that highly impacts on the final price of the robot.

Structured environment

To facilitate the use of robotic operations it is advisable to set some requirements on the environment structure (for example imposing accurate positioning of plants and pots) avoiding also autonomous navigation that is technically quite complex and has no real advantage. Rails or similar systems can work well simplifying the navigation tasks and reducing costs.

Reduced bulk and weight

High costs of greenhouses require that surfaces are used to the largest possible extent. For this reason it is important that the robot is little demanding in terms of surface that it diverts from productive activity. Similarly reduced weight can ease the installation of robots in existing structures allowing its possible hooking to existing plinths.

Scaling in size and operating volume

Scaling in size and operating volume should be foreseen in the design son that flexible adaptation to existing structures with different shapes and dimensions is made possible.

Vision system

Availability of an artificial vision system is highly recommended. It can enable surveillance and crop monitoring actions to be exploited for increasing quality and productivity. Moreover a vision system can also be used for obstacle detection and guidance in those cases in which the environment cannot be fully structured.

Versatility

The robot to be designed needs to be versatile and able to perform several different cultural operations with an easy conversion from one to another. In this way it could be possible to (almost) automate the entire production cycle of some cultivations.

Finally, cost should be kept as low as possible. The features discussed so far clearly show fundamental differences between the characteristics required for robots to be used in agriculture and those required for robots to be used in manufacturing applications. For applications in agriculture specific robot prototypes should be built and tested in research activity. As research tools these robots do not need to satisfy all the constraints required for a commercial product (in terms of costs, simplicity, performances, etc.) since these topics can be delegated to a future engineering phase, but they should allow to test a great variety of applications.

Robots development

Following the above design guide lines two different robotic cells prototypes for greenhouse applications were designed and implemented. Research activity was in particular focused to the development of multi-purpose robots able to perform different operation on crops changing tools and software configuration. Particular care was also dedicated to the implementation of an artificial vision system for crops detection integrated with the manipulators axis control.

In the following, the characteristics of the two prototypes as well as of the control systems are described.

Fixed point robotic cell

The first robot prototype was designed to operate in fixed position, interfaced to a belt-conveyor displacement system which provides to the robot pallets containing the crop, usually in pots (Belforte et al, 2006).

It consisted of three degrees of freedom manipulator that can be equipped with different end-effectors and tools adding further degrees of freedom to the system (Fig.1). Since the robotic cell was conceived to work in a fixed position, the longitudinal movement, orthogonal to the displacement direction of benches (Fig. 2), is performed by a pantograph mechanical structure. This solution reduces the back side play and limits the overall encumber of the manipulator as much as possible, reducing unproductive volumes within the greenhouse.

The mechanical structure was assembled using standard steel tubes with square and rectangular hollow, whereas each of the three joint was drive by an endless screw electric linear actuator. The employment of simple and commercial components, therefore, led to a low cost manipulator, fullfittening the previous indications.

If on the one hand a pantograph structure ensure limited encumbers, on the other hand this solution presents some drawbacks which limit the manipulator performances, in particular production rates and load capability. From the kinematics point of view, this kind of mechanical structure indeed turns out to be rather complex, therefore high computational resources for the kinematics inversion are required to the robot control system (Belforte et al, 2006; Belforte et al, 2007). This fact significantly increases the elaboration times for trajectory generation, reducing the operating rate.

Figure 1. Fixed point robotic cell operating in the greenhouse.

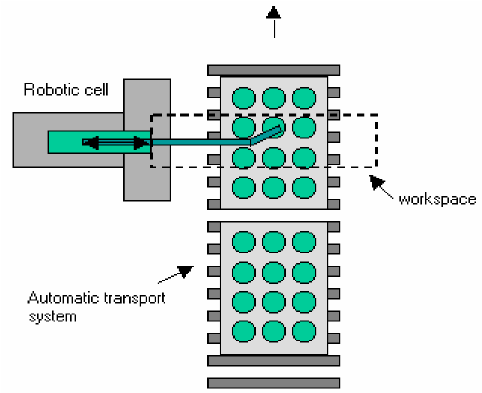

Figure 2. Layout of the robotic cell interfaced with bench displacement system

Cartesian robotic cell

On the basis of the experience acquired with the first prototype, a second robotic cell was designed and implemented with a different mechanical structure in order to increase productivity performances and versatility. This second robotic cell, in fact, was conceived with particular regard to flexibility in term of adaptation to different crops, greenhouses sizes and operating volumes.

Among the different possible solutions (anthropomorphic, scara, Cartesian, etc.), in this case, a Cartesian configuration was chosen. Usually, in fact, crops are distributed on rectangular benches or rectangular portion of soil, so their position can be easily identified in a three coordinate Cartesian reference. In this way the position of target objects (crops or part of them) can be directly translated into joints coordinates without inverse kinematics problems. A Cartesian structure, furthermore, allows the employment of commercial technical solutions, both regarding axis controller devices and mechanical components, properly designed for this kind of configuration (Belforte *et al*, 2007).

Second robotic cell consist of a Cartesian tool handler module, assembled with belt linear actuator, that can be installed on different structures to allow its displacement through the greenhouse. With the employment of belt linear actuator it is possible to assemble robotic cells with different size easy-fitting to different greenhouse structure or crops variety.

During the design phase a number of Cartesian tool handler displacement solutions are considered and evaluated. The high degree of flexibility of the Cartesian module allows its installation in different retaining structures, both moving and fixed, exploiting the existing greenhouse structures (plinths, floors, trusses, etc.) as reported in Figure 3. Details about features and limits of the different assembling configurations are widely discussed in Belforte *et al* (2007).

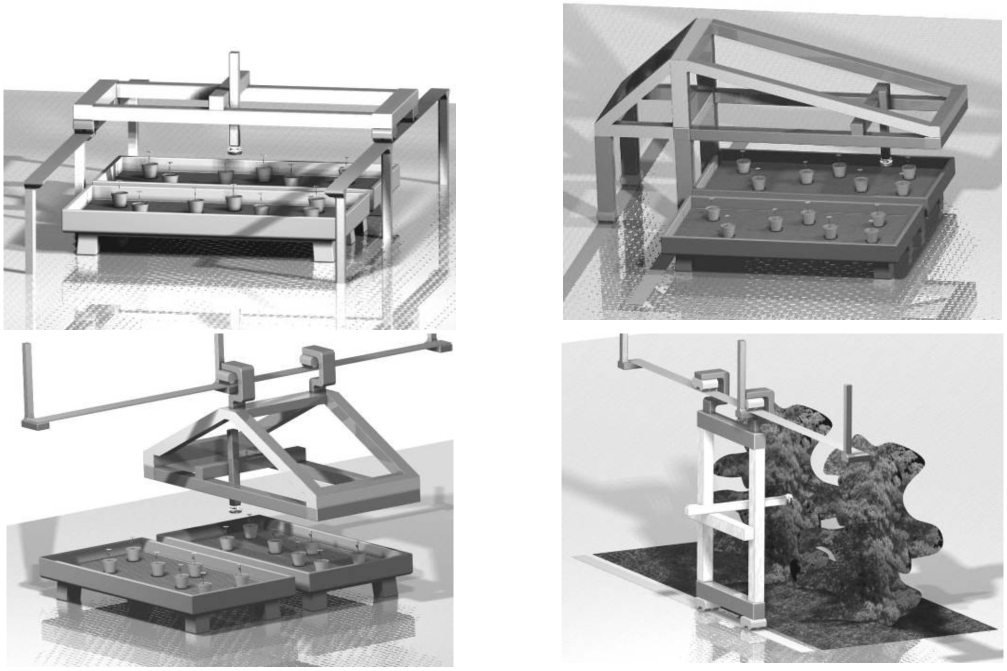

Figure 3. Some examples of different assembling configuration of the Cartesian robot

Actually, Cartesian module is installed on a gantry structure. This solution allows both a fixed point configuration, in which the robotic cell is interfaced with a standard benches displacement system, and a mobile configuration by means rails fixed on greenhouse floor.

The developed prototype was got into proportion to cover the entire surface of a typical greenhouse bench, with an overall working space of about 3000x1500x1000 mm (see Fig. 4).

The Cartesian module was also gifted with a further degree of freedom which allows a tool rotation around its own axis. Mechanical structure of this fourth axis was designed to perform light tillage such as mechanical weed control; moreover a pneumatic tool holder was installed on its end to take the end-effectors in an automatic way, minimizing the number of manual operations (Fig. 5).

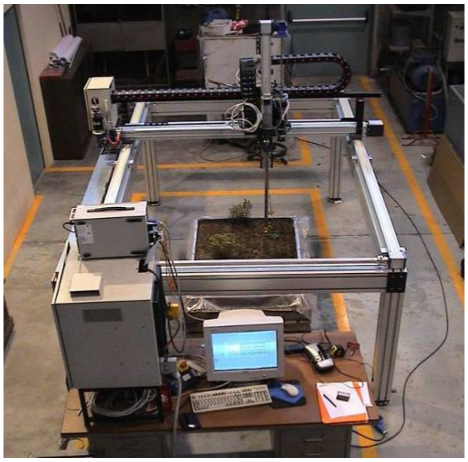

Figure 4. Cartesian robotic cell installed on the gantry structure.

Figure 5. Detail of the fourth axis.

<u>*Artificial vision system and robots control*</u>

Robots control systems followed the same architecture in both prototypes. They were designed and implemented with the aim to integrate the trajectory generation of each axis with an artificial vision system for crops identification and their localization within the robot working area.

Artificial vision system was set up in way of to film the same portion of the robot workspace both in the range of the visible light and in the band of Near Infrared (NIR). In this last band of the electromagnetic spectrum, in fact, vegetation shows a very high value of reflectance. This feature is exploited in many applications to implement different crop identification algorithm.

For this reason two identical single 1/3" CCD cameras are installed on the robots. It is important to underline that no specific camera for NIR image acquisition was used, because CCD sensor is sensible in this band too. However, to cut visible light component from NIR acquisitions an appropriate filter was mounted on camera lens.

Elaborating the images acquired by means the two cameras with appropriate algorithm and merging information, it was possible to well separate crops from the background also in variable light conditions.

Tools and experimentation

Besides tests aimed to the control systems calibration, in particular of the artificial vision system, and the performances evaluation of the developed robotic cells, a number of end-effectors, with the required management software, were implemented to perform different operations on crops.

Tools implementation was focused on operations dangerous for operators health, such as chemicals distribution, or that require an high manpower employment (products handling, mechanical weed control, etc).

First prototype was tested in real operating conditions in a greenhouse of CeRSAA centre situated in Albenga (Italy), carrying out an under leaf spraying on cyclamens and a precise granular fertilization on pot crops.

Regarding with Cartesian robotic cell, the experimentation is actually at laboratory level even if some operations, in which the additional degree of freedom of the fourth axis was exploited, have been already implemented. In particular were developed and tested with promising results a passive grab for square section pots displacement, a weed control tool and a crop duster for precise spraying.

Conclusions

In the present work the problem of the introduction and diffusion of robotic was faced. Analyzing carefully the reasons that have prevented the employment of robotic systems in agriculture so far, some important guide lines to design agricultural robots was introduced. Among these, the capability to perform different tasks appears the most important feature for a robotic system conceived to operate in the agricultural context. Moreover, greenhouses are indeed the most suitable agricultural environment to the introduction of robotic systems for several technical end economical reasons.

Research activity led to the development of two robotic cells prototypes for greenhouse applications able to perform different operations on crops changing tools and software configuration. During their experimentation, both in laboratory and in a real productive context, different operations on crops were implemented and tested with very promising results.

Obtained results have proved the validity of the followed approach. The development of robots specifically conceived for agricultural applications, which feature well fit with the specific productive context, could lead to a real diffusion of robotic systems in this sector already in the next future.

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