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“Assistive technology”

“Logistic in agro-food supply-chain”

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ORAL PRESENTATION

An Assistive Technology Application for Narrow Tractors ROPS

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Keywords: foldable safety frames, automatic tilting, slope, orchard and vineyard

Objectives

Assistive Technology (AT) is nowadays commonly used not only referring to rehabilitative devices, but also for those able-bodied find useful. Technology is so often created without regard to people with disabilities.

On narrow track tractors, typically used in orchards and vineyards, a simple two-pillars front mounted roll bar is frequently fitted for safety reasons, being it tiltable in order to allow travelling the machine between rows without damaging the low branches.

Its correct operation requires the operator takes an active role in making sure the ROPS is properly adjusted when not in a low clearance situation; that is a task some operators may not consistently perform, and the result is a permanent arrangement of the roll bar in its horizontal position, so that the protection provided in case of an overturn is completely wasted.

Methods

Some solutions were recently found in order to avoid operator's intervention to perform the described operation, with two different automation levels:

- 1) an aided execution, carried out through specific devices, electrically, hydraulically or pneumatically driven;
- 2) a completely automatic execution, using the above specified devices, but activated only if an overturning occurs.

Relevant to this last possibility, some devices were recently proposed. In the USA, NIOSH has developed the AutoROPS, a safety frame passively controlled, staying in a lowered position until a rollover condition is determined, at which time it deploys to a fully extended and locked position.

In Turkey, Tam Test developed a device including automatically deployable bars welded at the top of a two pillars front mounted roll bar for narrow tractors, able to stop the continuous rollover thanks to its penetration into the soil.

Results

On the other hand, the tilting operations of the roll bar could be usefully carried out with a simple device, consisting in a hydraulic cylinder welded on one of the two pillars at an extremity, and to the relevant mounting of the ROPS at the opposite one. If a new fitting is provided, the cylinder could be driven via a dedicated circuit, while in case of retrofitting one the connectors of the tractor hydraulic circuit should be considered.

Some experimental samples in retrofitting applications were arranged and positively tested on narrow track tractors, as in view to verify their functionality, as in order to define the best ROPS tilting speed.

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 *et al*, 2003; Van Henten *et 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 so 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, fullfitting 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.

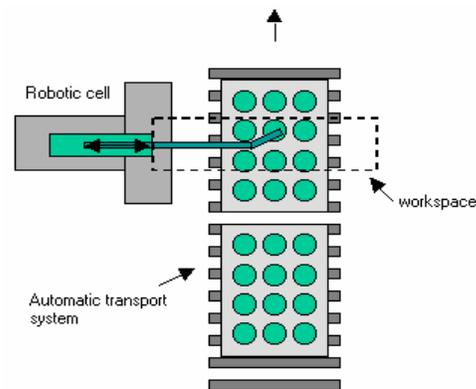


Figure 2. Layout of the robotic cell interfaced with bench displacement system

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).

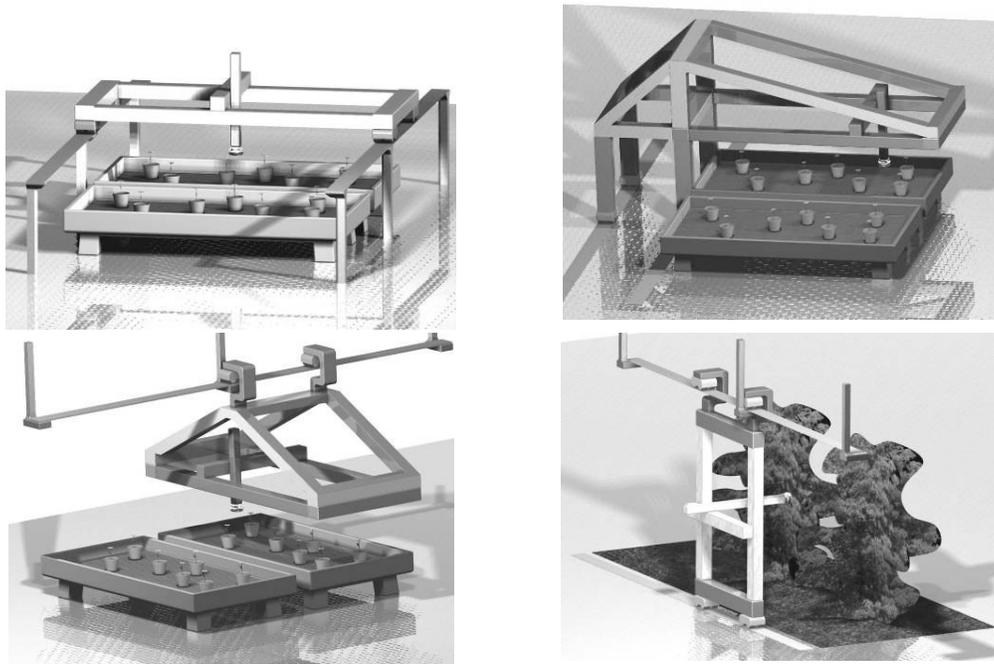


Figure 3. Some examples of different assembling configuration of the Cartesian robot

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).

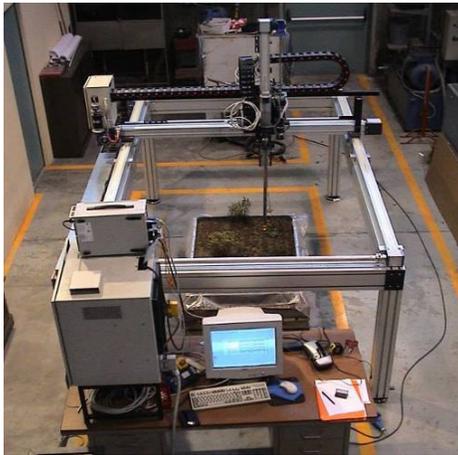


Figure 4. Cartesian robotic cell installed on the gantry structure. **Figure 5. Detail of the fourth axis.**

Artificial vision system and robots control

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 and 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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Logistic strategies for segregation of Identity Preserved grain during unloading operations: assessment by means of network simulation

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Abstract

The objective of this paper is to investigate the network modeling technique as an innovative system useful for analyzing the interaction between the grain elevator and the farmers who carry grain to the facility. In this investigation, network modeling was used to compare the performances of the four elevator strategies that characterize a large inland elevator in Delphi, IN, USA. The strategies examined were: baseline scenario, one-pit enlargement, two-pit enlargement, and traffic pattern change. The network model simulates unloading activities inside the elevator, farm activities (harvesting and transportation to the elevator), as well as the interactions between these two systems. The link between the elevator and traffic subsystem models allows for the analysis of the elevator performance by also taking into account the performance of the farmer and vice-versa. The software used to build the simulation model was Extend® (ImagineThat Inc., Palo Alto, CA, USA). The Average Service Time [AST] of the trucks was used as the indicator performance to compare the system performance with different strategies. The network model Scenario 1 predicted AST savings for a daily grain volume that could occur during the season (average, busy and peak day). The savings were 32% for the one pit enlargement, 38% for the two pits enlargement, and 23% for the traffic pattern change compared to the baseline scenario. The network model Scenario 2 predicted near-maximum performance of the elevator strategies. The results showed that the two-pit enlargement was best and allowed for dumping of up to 76 loads.day⁻¹ resulting in a 16.7% increase compared to the baseline scenario (i.e., The AST savings were 34.6 min.truck⁻¹ vs. baseline scenario (i.e., 34.0%). The results showed that grain distribution also had important influence on the performance of unloading operations. The network modeling approach could be used to investigate the regional impact of harvest-transport operations (bigger combines, field-to-field yield variability, transportation speed effects, etc.), management practices and resources availability on farmers as well as the unloading operations of multiple grain facilities all simulated in one large-scale model. The performance of the system could be evaluated both on farm and elevator side.

Keywords: Logistics, network simulation, grain segregation

Introduction

Before the availability and common use of hopper bottom semi truck trailers, many Midwestern grain elevators improved their receiving capacities in the mid-1970s by adding hoisting stations that incorporated platform scales at their unloading pits.

Although pit holding capacities gradually increased to hold 10 t or more (a typical gravity wagon holds about 7.5 t, a single axle farm truck holds about 6 t, a two-axle truck about 10 t, and a straight semi trailer about 25 t), pit dimensions were designed to accommodate unloading from gravity wagons, trucks and trailers with rear gates.

The existing pit dimensions require that these trailers have to be moved during unloading at least once to align the hopper outlet over the pit. When trucks are weighed using existing hoist-based platform scales, they have to pass the receiving pit to be weighed full,

then back up twice to align the first and then second hopper over the pit, and finally pull ahead again onto the platform scale to be weighed empty.

Multiple segregations of grain types require more cleanout cycles of the receiving equipment, which reduces unloading capacity and increases average service times (Berruto and Maier, 2001). Thus, in order to minimize them and maintain customer satisfaction, truck movement through the facility must be as efficient as possible. Longer service times must also be avoided in order to minimize the operating costs of the unloading system and for the elevator to remain competitive with respect to its local market share (Dooley and Wilson, 1987). Previously, the elevator system model began with the truck arriving at the elevator full and ended when it left empty (Berruto and Maier 2000, 2001). The time and frequency of truck travel from the elevator to the field and its impact on average service time and maximum elevator receiving capacity was not considered. In fact, if the elevator was serving the farmers faster, they would return more quickly and frequently. The fast service lowers the cycle times, increases the number of return trips per day, and results in more grain deliveries to the elevator.

The objective of this study was to utilize the network modeling approach to analyze the interaction between the grain elevator receiving operations and the travel time and arrival frequency of trucks carrying grain from fields to a large inland terminal elevator. Specifically, the following aspects were investigated:

- the expected maximum receiving capacity of the elevator as a result of the proposed logistic improvements;
- the effect of logistic improvements at the elevator on the reduction of the average service time and increase of the delivery frequency on individual customers.

Material and methods

Elevator description

The elevator consists of a single probing station near the main building, two 35 t receiving pits, two hoisting stations with integrated platform scales, 18 concrete silos (1250 t each), 5 welded steel tanks (12500 t each) and a 45000 t outdoor pile. The actual facility layout is presented in Figure 1.

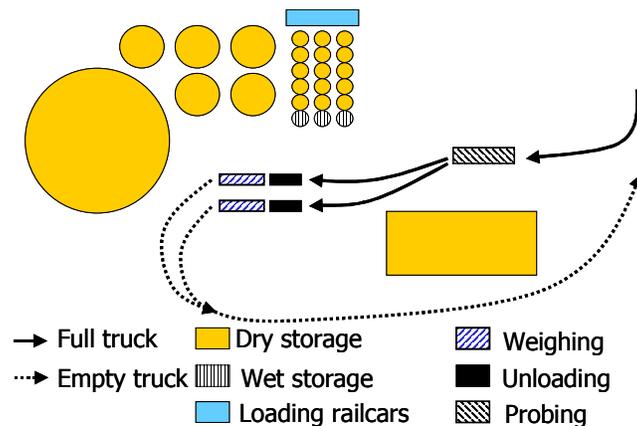


Figure 1. Layout of the commercial grain elevator surveyed in this study. The layout and the traffic pattern do not change for the enlargement of one or two pits.

In order to simulate the traffic outside of the elevator, the network model required three statistical distributions that defined the pattern of each daily traffic volume. Based on the analysis of the scale ticket data, the following distributions were estimated:

- the cycle time required for the trip to be made from the outbound gate of the elevator to the field and back to the inbound gate of the elevator;
- the inter arrival time between different trucks coming for the first unloading;
- the daily number of grain loads delivered per truck.

The goodness of fit test of the estimated distributions was done with the Kolmogorov-Smirnov test. The parameters related to the distributions that resulted from the statistical analysis using the SAS® software package are presented in Table 1.

Table 1. Parameter values for the statistical distribution related to the traffic model for three daily grain delivery volumes: average, busy and peak day.

Parameter	Units	Average	Busy	Peak
Different trucks per day:				
Number		82	107	129
Truck first arrival distribution:				
Type		Lognormal	Lognormal	Lognormal
Scale	(min)	9.73	8.11	6.62
Shape	(min)	4.48	3.94	3.32
Cycle time distribution:				
Type		Lognormal	Lognormal	Lognormal
Scale	(min)	101.49	98.49	85.62
Shape	(min)	6.29	6.29	8.58
Loads per day per truck distribution:				
Type		Poisson	Poisson	Poisson
Mean	(loads.day ⁻¹ .truck ⁻¹)	1.29	1.36	1.99
Actual avg. number of loads per truck per day				
	(loads.day ⁻¹ .truck ⁻¹)	2.29	2.36	2.99
Total number of load per day				
	(loads.day ⁻¹)	187	252	385

Proposed strategies to improve the grain receiving operation

Four receiving configuration and traffic management strategies were evaluated with the network simulation model:

- Strategy A. Actual configuration as depicted in Figure 1. The elevator had two pits and one probing station. The pits are not large enough to allow the unload of semi-truck without moving it. These pits allows to dump 13.1 trucks·hour⁻¹.
- Strategy B. One pit enlargement. where one pit was enlarged so that both hoppers of a semi truck trailer can be unloaded into the pit simultaneously. The enlarged pit could unload both trailer hoppers simultaneously, which increased its theoretical receiving capacity to 20.5 trucks·hour⁻¹. This resulted in a receiving capacity of 33.6 trucks·hour⁻¹ for both pits.
- Strategy C. Two pits enlargement, where both of the available pits were enlarged in the manner described under Strategy B. Each pit could handle up to 20.5 trucks·hour⁻¹, which increased the simulated receiving capacity to 41 trucks·hour⁻¹ for both pits combined.

- Strategy D. Traffic pattern change, which involves the relocation of the probing station and the addition of a scale for empty trucks. In this case, 15.1 to 16.7 trucks.hour⁻¹ per receiving pit could be dumped based on a time motion study for the weighing full-unloading operation. This yielded 31 to 33.3 trucks.hour⁻¹ considering both pits. The change in the layout of the elevator is presented in Figure 2.

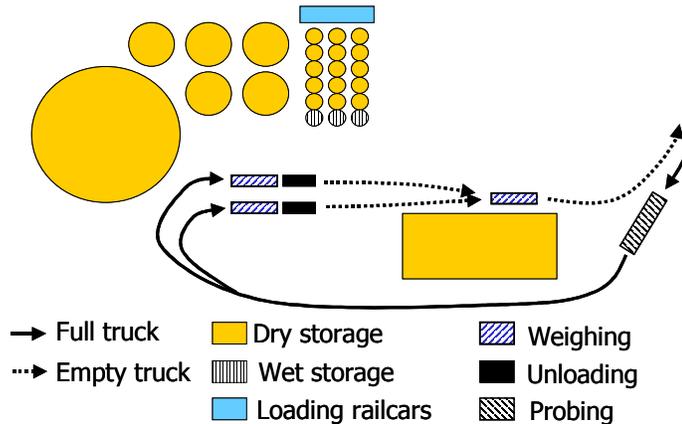


Figure 2. Layout of the elevator for the traffic pattern change. This layout presents a different traffic pattern and requires the relocation of the probing station and the addition of one scale for empty trucks.

Network model

The term network model will subsequently be used to emphasize the importance of interactions between the components of the system model that are affected by the traveling speed and distance and the elevator operation (Figure 3).

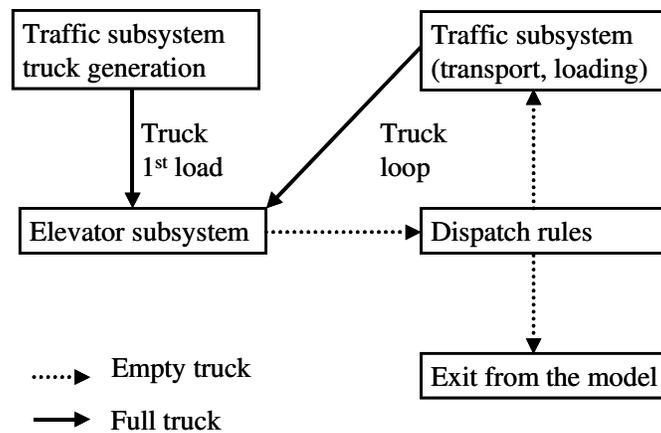


Figure 3. Schematic view of the grain elevator network model.

Network modeling considers the traffic outside of the elevator and generates arrivals over the day as a function of traffic parameters such as number of trips per day and traveling time for each trip. The link between the elevator and traffic subsystem models allows for the analysis of the elevator performance taking into account the farmer performance and vice-

versa. The software used to build the simulation model was Extend® (ImagineThat Inc., Palo Alto, CA, USA). Extend is a discrete event simulation software (Law & Kelton, 2000).

The trucks are generated according to the first arrival distribution (see Table 1) by the traffic subsystem truck generation model.

The truck is then sent to the elevator subsystem for the grain unloading operation. When the truck arrives at the elevator inbound gate, it is moved through the elevator subsystem according to the elevator rules and resources during the unloading process.

At the exit of the elevator, the dispatch rules are verified, in order to check if the truck has to take another load to the elevator, or has to leave the model.

The dispatching rules, verified sequentially, provide two ways for limiting the loads carried by a single truck to the elevator:

1. Rule1. Each truck cannot bring more grain loads to the elevator than the loads assigned to it when it was generated, according to the parameters of Table 1. When the truck has delivered the assigned loads, it exits from the model.

2. Rule 2. Each truck has to reach the elevator inbound gate within the operation hours of the facility. If the rule is verified, the truck is sent to the traffic subsystem, otherwise it exits from the model.

The network scenarios simulated were the following:

- Network Scenario 1, in which both rules above described have to be satisfied.
- Network Scenario 2, resulting from the combination of Rule 2 with a maximum of 10 loads per day per truck, which was the maximum observed for the truck arrival frequency of any customer. Scenario 2 represents the theoretical maximum capacity of the grain harvest-transport chain that comes to the elevator on a particular day, assuming customers will deliver as much grain as they can to take full advantage of the available elevator receiving capacity. In this case, the model results predict the near maximum of the elevator-harvesting-transport system capacity.

Experiments

A summary of the simulation experiments is presented in Table 2.

Table 2. Simulation experiments and parameters used to test the elevator logistic strategies.

Parameter	Exp. 1-12	Exp. 13-24	Exp. 25-36	Exp. 37-48
Daily truck volume	Average, Busy, Peak	Average, Busy, Peak	Average, Busy, Peak	Average, Busy, Peak
Grain distribution	GrainA	GrainB	GrainA	GrainB
Network scenario	Scenario 1	Scenario 1	Scenario 2	Scenario 2
Elevator strategy ⁽¹⁾	A,B,C,D	A,B,C,D	A,B,C,D	A,B,C,D
Simulation runs	1200	1200	1200	1200

⁽¹⁾ A- Actual configuration, B-One enlarged pit, C-Two enlarged pits, D-Traffic pattern change

While Network Scenario 1 yielded a total number of loads per truck per day similar to those determined from the scale ticket data for average, busy and peak days (2.29, 2.36 and 2.99 loads per day per truck, respectively), Scenario 2 always predicted a day busier than the peak day.

Two grain type distributions (defined as GrainA and GrainB) were used in the simulated experiments. They were chosen based on scale ticket data gathered from the elevator surveyed, and pit management was decided by the operations manager as follows:

- GrainA represented a grain type distribution of 55.6% dry corn, 22.4% wet corn and 22.0% soybeans, which was typical for the late harvest season when fewer soybean acres were harvested. In this case, pit #2 was reserved for the dry corn and pit #1 was designated for wet corn and soybeans. Thus, about 56% of the incoming grain volume was served by pit #2, while 44% was served by pit #1.

- GrainB represented a grain type distribution of 29.1% dry corn, 40.4% wet corn and 30.5% soybeans, which was typical for the middle of the harvest season. In this case, pit #2 was reserved for the wet corn and pit #1 was designated for dry corn and soybeans. About 40% of the incoming grain volume was served by pit #2, while 60% was served by pit #1. For Strategy B, the assignment of the pit was different than for the other strategies. The enlarged pit was reserved for dry corn and soybeans (59.6% of the total flow) and the regular pit for wet corn (40.4%).

Results

Network model Scenario 1

In this scenario, the daily number of loads per truck was fixed and so was the daily receiving capacity of the elevator. For this scenario, only the AST savings for the proposed elevator configuration and management strategies are shown in Table 3 where the data are presented according to the day volume - average, busy and peak day.

Table 3. Average service times (min.truck⁻¹) for the four elevator strategies for Scenario 1 and AST savings (min.truck⁻¹ and percentage).

Scenarios	Average	GrainA		Average	GrainB	
		Busy	Peak		Busy	Peak
A ⁽¹⁾	9.5 a ⁽²⁾	10.6 e	19.5 h	9.8 l	13.6 p	44.1 t
B	7.7 bc	8.2 fg	10.7 j	8.3 m	10.0 qr	29.0 v
C	6.8 c	7.2 g	9.1 k	7.3 m	9.3 r	27.6 w
D	8.1 b	8.9 f	13.4 i	8.5 lm	10.9 q	33.1 u
A-B (min) ⁽³⁾	1.8	2.4	8.8	1.5	3.6	15.1
A-C (min)	2.6	3.4	10.4	2.5	4.3	16.4
A-D (min)	1.3	1.7	6.1	1.3	2.7	11.0
A-B(% ⁽⁴⁾)	19.2%	23.0%	45.2%	15.5%	26.7%	34.2%
A-C(%)	28.0%	32.2%	53.2%	25.7%	31.5%	37.3%
A-D(%)	14.0%	16.0%	31.5%	13.0%	19.9%	24.9%

¹A- Baseline, B-One enlarged pit, C-Two enlarged pits, D-Traffic pattern change. AST are presented in min.truck⁻¹

²Values with the same letter are not significantly different at the 95% confidence level within the same incoming grain stream. Statistical comparison is valid just within the same incoming grain stream and thus the same column (same grain type and daily traffic volume).

³AST savings vs. Strategy A (min.truck⁻¹)

⁴AST savings vs. Strategy A (%)

For what concern the different elevator strategies, the network model for the Strategy A (baseline, no modification in the elevator) yielded 20.0 min.truck⁻¹.

The proposed new strategies yielded overall the following average service times:

- the one enlarged pit (Strategy B) yielded 13.5 min.truck⁻¹ (32% reduction vs. Strategy A);
- the two enlarged pits (Strategy C) yielded 12.4 min.truck⁻¹ (38% reduction vs. Strategy A);
- the traffic pattern change (Strategy D) yielded 15.4 min.truck⁻¹ (23% reduction vs. Strategy A).

The traffic pattern change yielded the lowest percentage savings, while enlarging both pits resulted in the greatest AST savings for all strategies evaluated.

Network model Scenario 2

This scenario identified the theoretical maximum capacity of the networked elevator-farmers system as a function of the elevator strategies and of the incoming grain stream. The number of daily loads received by the elevator is the first result that has to be pointed out for Scenario 2 of the network model. Therefore, the average number of load per day (Table 4) is much higher than the one presented in Table 1 (187, 252 and 385 respectively for average, busy and peak days parameters).

In this case, the number of daily loads delivered by the customers was not an input parameter as it was in the elevator model, and it was not limited per truck as in network Scenario 1.

The number of loads per truck and the daily loads were generated by the network model and represented the near-maximum performance of the inter-connected elevator-harvest-transport chain. The traffic subsystem (i.e., transportation and harvesting operations) is the same for the four elevator configuration strategies within the same incoming grain stream (i.e., daily traffic volume and grain type distribution). The number of loads received daily is directly influenced by the elevator performance. So, the better the strategy performs, the higher the number of daily loads delivered by the customers.

All new strategies yielded significantly better results than Strategy A.

The enlargement of one (Strategy B) or two pits (Strategy C) allowed for important increases in daily receiving capacity compared to the actual configuration, which was valuable information for the elevator manager.

Also, the grain type distribution and pit management had an important effect on the number of loads received daily:

- for the GrainA distribution the delivery increase due to the enlargement of one (Strategy B) or both pits (Strategy C) vs. Strategy A (actual configuration) was about 11.0 to 16.7% while the traffic pattern change (Strategy D) accounted for a 3.3-3.9% gain in grain received daily. The best strategy was enlargement of the two pits, with an increase up to 16.7% (76 loads.day⁻¹) compared to the actual elevator configuration performance (Strategy A). For the busy day, strategies B and C were not significantly different;
- for the GrainB distribution, the pit enlargement yielded a 5.7 to 7.2% increase (up to 30 loads.day⁻¹) vs. the actual configuration, while the traffic pattern change allowed for a 4.0 to 5.4% (up to 22 loads.day⁻¹) increase vs. the actual configuration. Strategy C was significantly better ($\alpha=0.05$) than Strategy D but not significantly different than Strategy B. For the peak day, the strategies B and D were not significantly different from each other.

The number of daily loads delivered to the elevator was also an important result with respect to the results related to the Average Service Times [AST].

Table 4. Daily receiving capacity of four elevator strategies for network Scenario 2 (loads.day⁻¹).

Scenarios	GrainA			GrainB		
	Average	Busy	Peak	Average	Busy	Peak
A ⁽¹⁾	373.8 d ⁽²⁾	413.4 g	455.2 k	347.6 n	382.9 r	416.4 v
B	414.9 b	463.5 f	519.2 i	369.3 l	404.6 p	443.2 tu
C	420.7 a	469.2 f	531.2 h	371.1 l	408.2 p	446.4 t
D	388.0 c	427.0 e	473.1 j	362.6 m	398.0 q	438.9 u
B-A ⁽³⁾	41.0	50.1	64.0	21.8	21.8	26.9
C-A	46.9	55.8	76.0	23.5	25.3	30.0
D-A	14.2	13.5	17.9	15.0	15.2	22.5
B-A(%) ⁽⁴⁾	11.0%	12.1%	14.1%	6.3%	5.7%	6.5%
C-A(%)	12.5%	13.5%	16.7%	6.8%	6.6%	7.2%
D-A(%)	3.8%	3.3%	3.9%	4.3%	4.0%	5.4%

¹A- Baseline, B-One enlarged pit, C-Two enlarged pits, D-Traffic pattern change

²Values with the same letter are not significantly different at 95% confidence level within the same incoming grain stream. Statistical comparison is valid just within the same incoming grain stream (same grain type daily traffic volume)

³Receiving capacity increase vs. the strategy A (loads.day⁻¹)

⁴Receiving capacity increase vs. the strategy A (%)

The three new strategies evaluated returned statistically significant ($\alpha=0.05$) lower AST values than the actual configuration (Strategy A), and the differences were significant among the strategies (Figure 4).

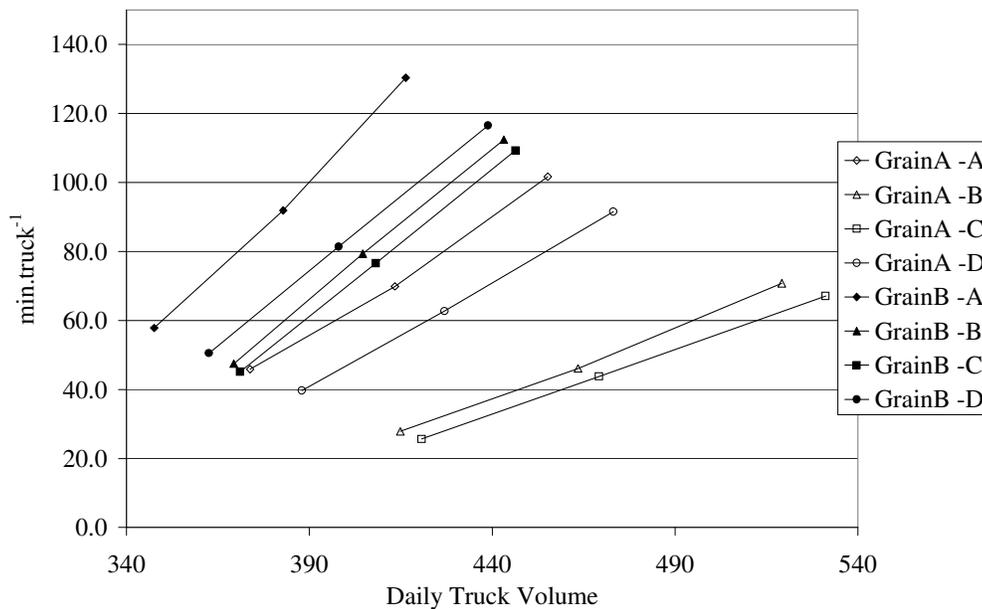


Figure 4. AST values for Scenario 2 and GrainA and GrainB distributions, for four simulated elevator strategies: baseline (A), one pit enlargement (B), two pits enlargement (C) and traffic pattern change (D).

Particularly:

- for the GrainA distribution, the AST savings due to the enlargement of one (Strategy B) or both pits (Strategy C) vs. Strategy A (actual configuration) was about 30.4 to 44.1% while the traffic pattern change (Strategy D) accounted for 10.0-13.4% AST reduction. The best strategy was the two pits enlargement, with AST savings up to 34.6 min.truck⁻¹ compared to the actual elevator configuration performance;
- for the GrainB distribution, the pit enlargements yielded up to 21.9% in AST savings vs. the actual configuration (Strategy A), while the traffic pattern change allowed for 10.6-12.6% in AST savings vs. the actual configuration;
- the savings in AST were larger for larger incoming grain flows.

Conclusions

The research presented the implementation of a network model to simulate the interaction of elevator grain receiving operations and grain truck deliveries from fields and farms. Four elevator configuration and traffic management strategies (baseline, one pit enlargement, two pits enlargement and traffic pattern change) were tested using the network model as a function of two different grain distributions and three daily traffic volumes.

The results of the simulation experiments showed that:

- the network model Scenario 1 predicted AST savings during a simulated grain flow that could occur during the season. The savings were 32% for the one pit enlargement, 38% for the two pits enlargement, and 23% for the traffic pattern change compared to the baseline;
- the network model Scenario 2 predicted near-maximum performance of the elevator strategies for GrainA distribution given a delivery limit of 10 loads per day per truck. The results showed that the enlargement of two pits was best and allowed for dumping of up to 76 loads.day⁻¹ (i.e., 16.7% increase) more than Strategy A (actual elevator configuration). The AST savings were 34.6 min.truck⁻¹ vs. Strategy A (i.e., 34.0%);
- the network model Scenario 2 predicted maximum performance of the elevator strategies for GrainB. The results showed that the enlargement of two pits was best and allowed for dumping of up to 30 loads.day⁻¹ more than Strategy A (i.e., 7.2% increase). The AST savings were 21.1 min.truck⁻¹ vs. Strategy A (i.e., 16.2%).

The network modeling approach could be used to investigate the regional impact of harvest-transport operations (bigger combines, field-to-field yield variability, transportation speed effects, etc.), management practices and resources availability on farmers as well as the unloading operations of multiple grain facilities all simulated in one large-scale model. The performance of the system could be evaluated both on farm and elevator side.

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Preliminary Study for the Development of an Electrical Autonomous Vehicle for Safe Agricultural Chemicals Distribution Inside Greenhouses

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Abstract

The main target of this research activity is to develop an autonomous electrical vehicle able to spray agricultural chemicals inside greenhouses. This vehicle can increase operations safety level for operators and quality of the chemicals distribution, allowing lower environmental pollution and better greenhouse product quality.

As future development, also the vehicle's chemicals tank refuelling operations will be remotely operated, because this step is one with the highest risk for the operators due to possible contact of the operators with huge quantity of chemicals.

During a first step, the activity will be focused on the development of the electrical vehicle with remote control wireless capabilities. After the vehicle will be fully tested, a distribution and refuelling unit with sensors will be developed and optimised for the specific application.

Feasibility tests have been done using an outdoor remotely operated rover available at DIEES Robotic Laboratory; these tests have demonstrated the goodness of the idea. Moreover, due to constant reduction of electronic parts cost, like computer and power control system and to the presence on the market of new low cost devices for precision farming, the development of a dedicated autonomous vehicle is not as expensive as in the past.

Key words

Robot, tomatoes, safety, precision farming

State of the art

Leaving out direct costs, agricultural chemicals distribution has huge impact on social cost due to the high risk level for operators and to possible environmental pollutions.

To mitigate these problems, in recent past, some semi-automatic distribution methodologies, based on some fixed facilities build inside each greenhouse, have been developed. These can operate without human intervention inside the greenhouse and are composed by a number of sliding rods with nozzles. Due to their high cost and huge impact on the greenhouse, they are not so common.

Because of greenhouses are highly structured and regular environment with respect to the open field, they are well suited to be operated by some automatic machines. Moreover the high risk level for operators has driven different research group to find some solutions like autonomous or teleoperated robotics systems; hereafter a survey of past project in the field will follow.

The AURORA robot (Spain) is able to perform different tasks in an autonomous way with remote supervision [1].

Within the Italian project AGROBOT, a mobile rover bringing a 6 DOF manipulator with an end-effectors and a ‘head’ with 2 DOF, was developed. The system is dedicated to tomato cultivation inside greenhouse. The robot is able to inspect each plant and to plan individual treatment. Moreover it can distinguish the different maturity level of the fruits. In order to solve navigation problem, some visual feedback have been used [2]. Other manipulator was developed to pick citrus fruit [3].

At University of Genova a project named “Mobile robots in greenhouse cultivation: inspection and treatment of plants” [4] has been developed. The main target of the system was to monitor the health status of the plantation in order to plan dedicated treatment with precision farming methodology. Moreover the system can monitor the chemicals concentration inside the greenhouse to signal the possibility for human operator to enter or not.

A mobile platform for greenhouse chemicals spraying is being developed at University of Almería [5].

A commercial machine, named Fumimatic 400 [6], is available in Spain. It is not autonomous nor teleoperated but has is a complete spraying machine with a powerful Diesel engine and a 400 l tank for chemicals.

An experimental test has been done inside a greenhouse (fig. 1) using the outdoor rover Robovolc [6]. It has six fully actuated wheels and has several CCD cameras and a remote base station that allow the system to be remotely operated. It was developed at University of Catania in the framework of a European project for volcanoes environments inspection. In spite of its dimensions, it has demonstrated a high degree of manoeuvrability also in very narrow passage. In any case the entire system has to be optimised for agricultural applications.



Figure. 1 – The Robovolc rover during tests inside a greenhouse

System specification

From analysing a typical spraying application inside greenhouses, a set of system specifications have been found.

The maximum width should be 0.8 m with typical greenhouse configuration. The minimum speed should be about 1.5 m/s while the maximum speed should be high enough to make fast chemical refuelling and system transfer on road. Because of short rows in the greenhouse, the robot must reach its target travel speed as soon as possible in order to guarantee uniform spraying as soon as possible in the row, so it should have a suitable acceleration.

At the end of each row, the robot must turn in order to re-enter next row. In order to turn using as less space as possible, the robot will use special kinematics manoeuvring, like skid steering. Moreover it will have not to damage the terrain or the plastic mulch. To not compress the terrain, the robot must use chain-like wheels; with this solution the pressure on the terrain could be less than 60 kPa considering the mass of the robot and the chemicals full tank weight. During system manoeuvring, spraying unit must be turned off. This should happen also in case of reverse motion or stop. An acoustic signal and security supervision module will be also available in order to allow the system to operate autonomously. A suitable high efficiency engine with very low pollution will be mounted on-board to provide electrical traction power and suitable spraying pressure.

The main structure of the system is represented by an electrical machine widely used in the south-east coast of Sicily [7]. This machine, named “Vanco”, is derived from some small manual trucks used in the past. It is actually used in helping human operation in outdoor operations as harvesting and to arrange cultivations (fig. 2).



Figure 2 – The “Vanco” system

The manufacturer, in collaboration with farmers, has so developed the electrical version of the trucks.

In the current implementation, it use two robust rubber chains with gearboxes instead of wheels, actuated by one brushed DC motor of about 630 W with 3000 RPM at no load conditions. The system has moreover a hydrostatic mechanical power distribution with two speed and reverse motion. The power supply is obtained from two series connected lead-acid 12 V, 180 Ah batteries. The weight of the metallic structure is about 100 kg while the total mass, including motor, gearboxes, the two batteries and so on, is about 300 kg. Because the

two batteries, DC motor and gearboxes are mounted on the lower part, the whole system can guarantee very high stability.

Thanks to the special shape of the two rubber chains, the system is able to overcome obstacles and to move over concrete tracks as well as over rough terrain.

Project steps

The design of the system will be performed in different steps. Mainly, first the mobile rover will be realised; after that the navigation and the spraying systems will be developed.

The rover will accomplish the specification described before and its functionality could be synthesised as:

- Should be able to deftly move inside the greenhouse;
- Should be able to carry the spraying unit and all the necessary devices and their weight;
- Should not damage greenhouse and related facilities;
- Should be at least teleoperated or autonomous.

After the rover has been tested, all the device related to remote operation and to autonomous navigation will be developed.

The navigation subsystem will comprise two different modes:

- Remote control, in which the user will send command to the rover from a safe place outside the greenhouse;
- Autonomous navigation, in which the user will program some tasks for the robot and then these tasks will be autonomously performed by the robot.

The system will be able to store at predefined time step its position and the related spraying flow in order to allow treatment traceability.

In Fig. 3 it is shown a block diagram of the system. Among the most important blocks there are the “*User Interface*“ that allow the operator to plan the mission in autonomous mode or to send direct command to the whole system (rover and spraying unit) in teleoperated mode and in any case to receive system status. It is wireless connected to the robot and can receive video information taken from the on-board cameras.

The block named “*Task Generator*” translate user command (sent in an high level language) into low level command sequence for the system. The block named “*Trajectory Generator*“ calculate the system trajectory in autonomous mode, on the base of the assigned task and on the greenhouse map. The block named “*Map Database*”, holds all the map of the greenhouses where the system will be used inside. The block named “*Obstacle Avoidance*” is responsible to detect and to warn about unexpected obstacles. The block named “*Localization*“ will allow system localization inside the greenhouse using triangulation methodology. The block named “*Traceability Database*” will store position of the robot and related sprayed flow for post-processing purpose.

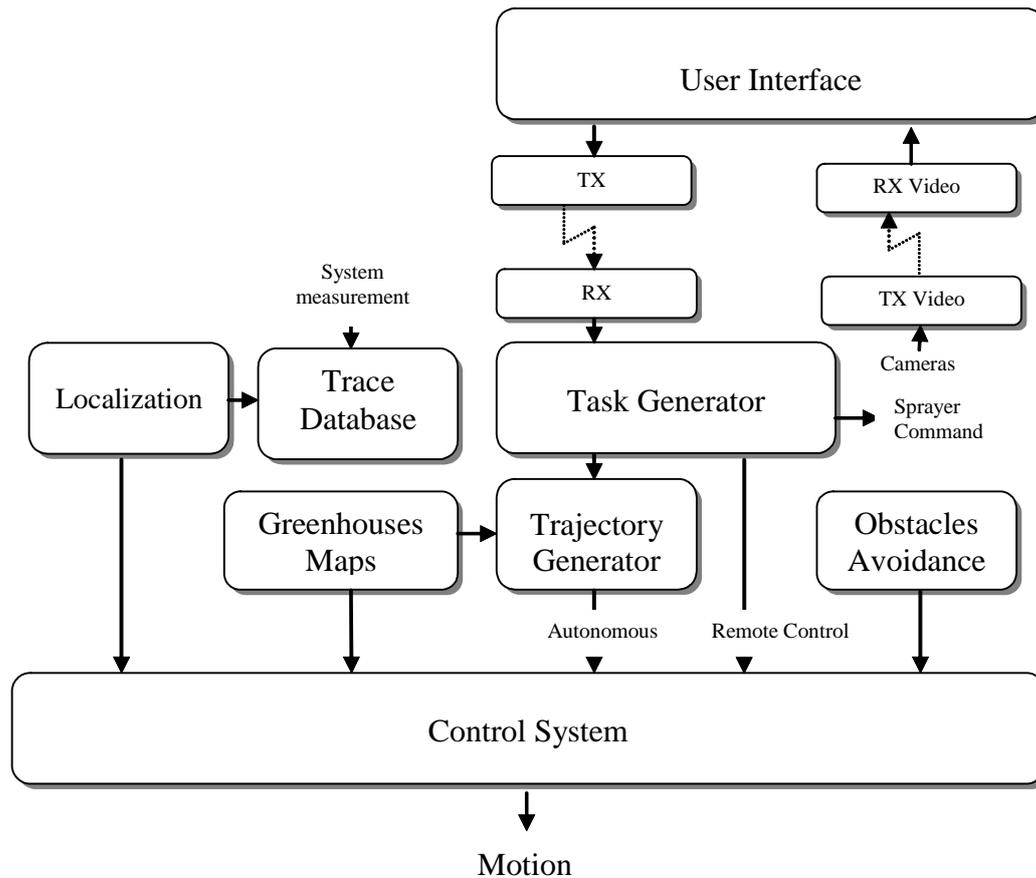


Figure 3. Block diagram for the main functionality of the system

Results

Expected results from this activity are a rover able to move inside different kind of greenhouses with actuators and a control system for remote/autonomous operations. Moreover a navigation/localization system will be implemented on-board; this capability will allow traceability of treatment as required by the precision farming methodology and will guarantee safe system operation inside the greenhouse also in case of unexpected situations. The system will be completed with a spraying unit, a tank for chemicals, control system for the hydraulic components, filters and so on.

Using this kind of robot, one could expect to increment the efficiency of each operation of about four times when the system in autonomous mode with respect to a team of 6-7 worker. In standard conditions this team can spray about 1.8 ha in about three hours. This machine could operate also during night time in autonomous mode.

On the other side, using an autonomous machine for greenhouse spraying operation, it is avoided the exposition of worker to chemicals, also during refuelling operation that will be autonomous also, increasing the operators safety.

It can also be used by the farmer for other tasks than spraying by removing the tank and the spraying unit, so the cost of the whole system can be distributed along different areas of applications, attracting farmer towards this product.

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POSTER PRESENTATION

A Device for the automation of the engagement between tractor's power-take-off and PTO-drive shaft

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Abstract

Manually connecting and disconnecting the PTO-drive-shaft to the tractor's PTO are difficult operations, often executed in narrow spaces between tractor and operating machine and represent a source of risk of accidents. The automation of such operations would significantly contribute to improve the ergonomics in agricultural work. At a time, risks of accident would decrease as a consequence of the reduction of manual interventions.

This paper describes a device developed by MR-Industria Meccanica s.r.l., aimed at significantly reducing manual interventions during the connection/disconnection of the PTO-drive-shaft to the tractor's PTO, reporting the results of tests conducted at CRA-Ing. Although it has been proposed in 2002, the device is still of interest for the sectors of assistive technology, ergonomics and safety and probably deserves more attention and diffusion.

Keywords: automation, PTO-drive-shaft engagement.

Introduction

In the continuous updating of the components of agricultural tractors, the ergonomic aspects of the engagement of the PTO-drive shaft to the tractor's PTO became subject of a study that provided a device aimed at the automation of such operation.

Usually, the PTO-drive shaft is manually connected to the PTO with the operating machine mounted on the three point linkage. The narrow space in which the operation is executed determines discomfort and fatigue conditions for the operator that, at the same time, must lift and correctly place the drive-shaft on the PTO and push it until the connection occurs. This aspect is associated to the risk of accidents that could occur, mostly in field, during works requiring frequent engagements and disengagements of the PTO-drive shaft.

The impact of these aspects can be limited by reducing manual interventions. On purpose, a device has been developed and patented by MR-Industria Meccanica s.r.l. (Montone, PG, Italy) that allows to automatically execute most of connecting and disconnecting procedure.

This paper reports a description of the device and of its working mode and the results of some tests made with the aim of verifying its reliability and estimating the effects on the reduction of fatigue and discomfort. In the following it will be called MR-device.

Purpose

With the aim of substantially reducing manual interventions in the engagement and disengagement of the PTO-drive shaft with the tractor's PTO, the device has been designed as a frame independent from the PTO power transmission and, at the same time, for resisting to traction solicitations that would have the effect of extracting the drive-shaft power-input-connection (PIC) from the PTO tang during the work. By changing the shape and dimensions

of the steel plate supporting the standard elements of the mechanism, it can be mounted theoretically in all tractor models.

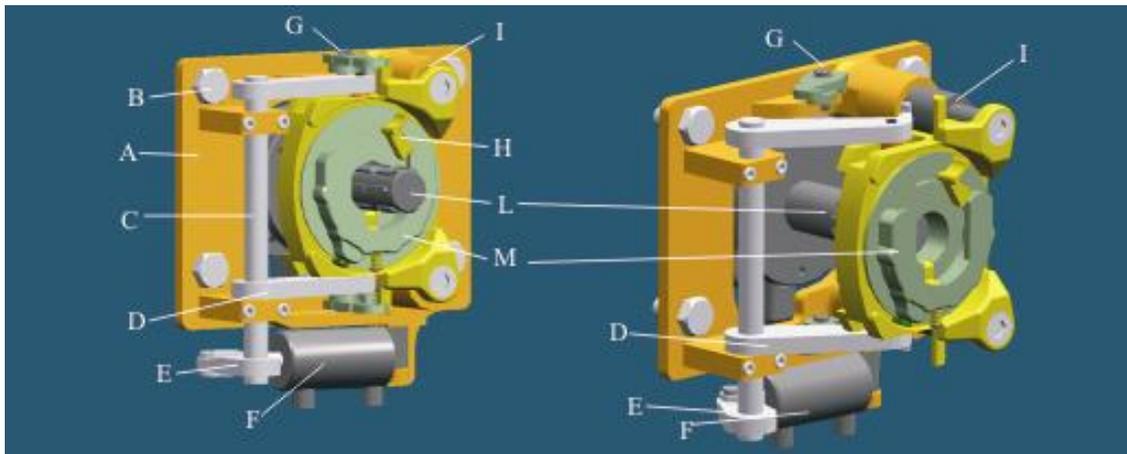


Figure 1. Sketches of the MR-device closed (left) and open (right), without PTO-drive shaft. A) support plate; B) fixing bolt; C) drive pivot; D) drive lever; E) drive crank; F) hydraulic cylinder; G) locking levers; H) wing-nut that lock the drive-shaft; I) telescopic guide bearings; L) PTO tang; M) PTO-drive shaft U-bracket

Description

The fig. 1 shows a sketch of the MR-device and of its main components. It consists of a steel plate supporting the mechanism that is driven by the tractor's hydraulic system and electronically controlled. After having installed the device on the tractor, the only manual operation required in connecting and disconnecting the PTO-drive shaft to the PTO is to insert the drive shaft PIC in the dedicated bracket of the device when it is in open position. The engagement or



Figure 2. The MR-device mounted on a tractor

disengagement between the PTO tang and the PIC is hydraulically operated and occurs respectively by forward and backward sliding of the bracket. Because of its reduced dimensions (width: 225 mm; height: 290 mm; length: 95 mm), it can be lodged

inside the frame surrounding the tow-hook that works as partial protection of the PTO (fig.2).



Figure 3. Original PTO tangs (below) and modified PTO tangs (above), 15 mm longer than the former, showing teeth with V-splayed edges

PTO tang and PTO drive-shaft PIC

The use of the MR-device requires a suitable PTO tang (provided by the manufacturer) 15 mm longer than the normal tang. The teeth of the modified tang have a V-splayed edge (fig. 3) facilitating the engagement of the similarly shaped teeth of the drive-shaft PIC (fig. 3). In order to reduce the friction and the cases of jam (that could occur when the apices of the teeth of the tang and of the drive-shaft PIC are perfectly in line, obstructing the drive shaft PIC sliding forward), some tang's teeth are slightly longer (for instance, in the six teeth tangs, two teeth are 3 mm longer than the others). Beyond the V-splayed PIC teeth, the drive-shaft must be modified as shown in fig. 4, in order to be lodged in the U-bracket of fig.1.

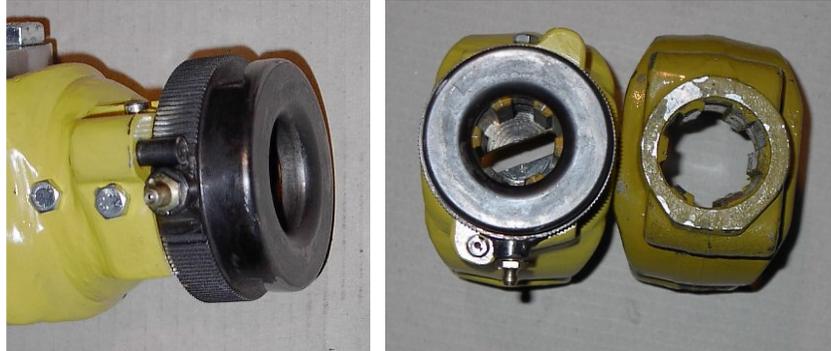


Figure 4. The PTO-drive shaft PIC presents a steel locknut shaped for being inserted in the U-bracket, as the teeth edges are V-splayed, like the tang teeth

Hydraulic system

The forward/backward sliding of the bracket along the PTO axis is operated by the action of a double effect hydraulic cylinder on a lever system. The cylinder is fed by the low-pressure hydraulic circuit of the tractor, through a two-ways electro-valve activated from the control board and directly connected to the tractor's electro-valve controlling the PTO, so that the engagement/disengagement can be executed only when the PTO is steady.



Figure 5. Control board on the cab of the tractor. G: green signal indicating the PTO-drive shaft engagement; R: red signal for the disengagement; J: joystick controlling the electro-hydraulic system; S: alarm turn-off

Electric system

The goal of the electric system is to manage the interventions of the electro-valve that controls the hydraulic cylinder depending on the signals sent by the sensors indicating the open / closed position of the device and the state of the PTO (rotating or steady). The control board is installed on the cab (Fig. 5) and presents a joystick controlling the engagement (green signal) and the disengagement (red signal). These operations can also be

executed from outside by means of two buttons on the rear fender of the tractor. Moreover, in order to reduce the risk of accidents, the system is capable to combine the signal of the position of the device with the sensor revealing the presence of the driver on the seat.

MR-device working way

The first operation, after its mounting on the tractor, is the manual connection of the PTO-drive shaft. The PTO must be off and the device must be in its open position. The connection foresees the following steps (fig. 6)

- The U-bracket on the device must be rotated until it locks in vertical position (concavity upward, figs. 6-a and 6-b);
- After having lifted the free end of the PTO-drive shaft, the locknut must be rotated as well until the grooves are in vertical position, so that they can be introduced in the U-bracket (figs. 6-c and 6-d);
- The locknut must be pushed downward until the wing-nut lock is on.



Figure 6. Operation sequence of the manual phase of the connection of the PTO-drive shaft to the MR-device

The manual phase is now concluded: the actual engagement between the drive-shaft and the PTO is operated by the electro-hydraulic mechanism controlled by means of the buttons described above. After the engagement, the PTO can start rotating.

Also the disconnecting of the PTO-drive shaft from the MR-device requests a manual interventions: after the work has been terminated, with the PTO off; the device must be opened disengaging the drive shaft from the PTO. It is now possible to remove the drive shaft end from the U-bracket, according the following steps:

- the group represented by the U-bracket and the locknut must be rotated until the groves are in vertical position (fig.7-a);
- by pressing the lever of the wing-nut lock, the locknut is released and can be extracted from the U-bracket: the disconnection has been completed (figs. 7-b and 7-c;)
- the MR-device should be closed again, after the disconnection, the in order to increase its compactness and protect the mechanism.



Figure 7. Operation sequence of the manual phase of the connection of the PTO-drive shaft to the MR-device

Tests on the MR-device

The tests regarded the reliability of the device, observing its behaviour during the execution of a high number of automatic engagement-disengagement cycles. Further observations regarded the easiness of use and the reduction of the fatigue and discomfort for the operator in comparison with manual connecting and disconnecting. Because of their nature, these last points could not be measured with instruments. The evaluation resulted from an accurate observation of the different phases of the operation compared with the manual operation commonly experienced. A relevant part of these observations regarded the use of the device during normal field work, also collecting the impressions of the farmers.

Reliability of the MR-device

The tests regarded the mechanism of engagement/disengagement, involving both the mechanic and electro-hydraulic components. They have been conducted using a test bench suitably developed, capable to continuously operate cycles of engagement/disengagement. The test bench (fig. 8) reproduces a tractor's PTO equipped with the MR-device and a modified PTO-drive shaft that must be engaged/disengaged on it.

The manual connecting and disconnecting between the PTO-drive shaft and the U-bracket of the MR-device on the test bench are identical to those described in the previous paragraph and the time intervals they require have been measured in these tests.



Figure 8. Test bench with the PTO-drive shaft connected and control board

their wear and lifetime as a consequence of eventual cases of jam. Finally, the test bench was equipped with a pressure relief valve aimed at releasing the hydraulic pressure when the jam occurred. As to the automatic engagement/disengagement, it is almost instantly operated when the control button is pressed. As a consequence, most of the attention has been pointed on the behaviour of the MR-device in performing a series of cycles repeated at interval of 3 s, observing the

The opposite part of the PTO-drive shaft had a traditional system for the connection with the PTO tang and has been use for observing the manual connecting/disconnecting. Instead of the low-pressure hydraulic system of the tractor, the MR-device was fed by a independent hydraulic pump electrically driven. The control board has been equipped with a timer allowing the automatic, continuous repetition of the desired number of cycles, at a pre-set time interval between two cycles. A spring-lever based mechanism determines, after every cycle, a random rotation of the PTO tang, with the aim of changing its position (referring to the drive shaft PIC), testing the efficiency of the V-splayed teeth in facilitating the engagement and observing

the efficiency of the V-splayed teeth in facilitating the engagement and observing



Figure 9. Tractor and operating machine during the field test of the MR-device

frequency of the jam events and consequently verifying the wear of the teeth.

Field tests on a tractor

The MR-device has been mounted on a New Holland M160 tractor coupled with a combined machine, for the sowing of wheat, with a rotary harrow. This consisted of 10 horizontal axis rotors with 25cm long tines. The working width was 3 m. The tests have been conducted on a previously ploughed, dry clay soil, with high slope values (fig.9).

The figure 10 shows some instants of the insertion of the PTO-drive shaft locknut into the bracket of the MR-device before starting the work.



Figure 10. Manual phase of the connection of the PTO-drive shaft to the MR-device mounted on a tractor before starting field work.

Test results

Test bench

The mean time required by the execution of the sequence of manual operations for the connection of the PTO drive shaft to the MR-device (fig. 6) has been 13 s, as for the manual disconnection (fig. 7) it has been 10 s.

As regards the automatic engagement/disengagement between the PTO-drive shaft PIC and the PTO tang, the complete cycle has been repeated 406 times, by means of the described test bench, corresponding, at least, to 1 years of traditional use. The observed cases of jam have been 28 (corresponding to 6.9% of the total) and have been overcome for effect of the described pressure relief valve. The V-shaped edges of the teeth did not show signs of damaging or wear.

Field

After an initial brief training, the operator became capable to easily execute the manual phase of the connection, requiring time intervals similar to those measured at the test bench. As previously said, the working conditions have been quite severe, with average PTO power requirements of about 90 kW. The frequent, abrupt changes of slope conditions, the high soil tenacity (depending on the high clay contents associated to the low humidity) and the surface unevenness determined frequent shocks on the PTO zone that, at any rate, did not affect the steadiness of the engagement between PTO tang and drive shaft PIC. The functionality of the

engagement/disengagement, tested several times during the work and at the end, kept in perfect efficiency, showing its reliability.

When the MR-device is installed on a tractor, it can not be provided with the "anti-jam" pressure relief valve because the thrust of the hydraulic cylinder could be insufficient to normal working for the presence of dust etc. If the jam occurs, it can be easily overcome by means of an instant PTO engagement that operates a slight rotation sufficient to unlock the apices of the jamming teeth.

Particularly positive have been the impressions of the operators that declared to find the device very useful in the reduction of the fatigue and discomfort determined by the manual connection of the PTO-drive shaft and considered it a valid support even from the point of view of safety.

Conclusions

The device reached the objective of the reduction of manual intervention in the connection on the PTO-drive shaft to the tractor PTO. After having equipped the tractor with it, manual intervention consists of the insertion of the drive-shaft locknut in a proper bracket on the device, as actual engagement/disengagement operations between the PTO tang and drive shaft PIC are controlled from the control board and electro-hydraulically operated every time it is needed. As a consequence, the time requested by the operations are significantly reduced and the conditions of fatigue and discomfort are substantially eliminated. Notwithstanding, as the traditional connecting and disconnecting operations depend on factors as the ability of the operators, the maintenance conditions of the machinery and their characteristics, it is difficult to provide an objective evaluation of said advantages.

The MR-device allows to automatically interrupt, from the cab, the transmission of PTO rotation and power, without detaching the PTO-drive shaft. This function can be used in different situations as during road transfers of the tractor-operating machine system, preventing mechanic damages.

Because of its easiness, the disengagement of the PTO-drive shaft PIC from the PTO tang could become a common practice, mostly in the cases in which it, normally, is not operated, preventing the risk of accidental PTO engagement, occurring, for instance, during the inspection of some parts of an operating machine after an inconvenient in field (as the flooding of a roller-baler).

In 2003, after a series of tests conducted by CRA-ING (Monterotondo, Rome), the MR-device obtained the ENAMA certification according to the "Protocol for the evaluation of the performances of the devices for coupling, towing and lifting systems - Cat. 40b" (ENAMA, 2003).

Greenhouse climate control using wireless sensors

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Abstract

The aim of this paper was to study the main ambient parameters inside a greenhouse with a modern wireless sensor network in order to reach the optimization of the production process.

The research was carried out in a greenhouse sited in Balestrate (in the province of Palermo, Sicily); the crop was courgette; the plants showed a high density distribution so that their vegetation took up a large part of the greenhouse area.

Inside the greenhouse a wireless sensor network made up of three node sensors was located. The sensors were located vertically in the middle cross section of the greenhouse both inside and outside the vegetation. This allows to obtain the microclimate inside the greenhouse and to verify the possible differences of the measured quantities among the three sensors in order to rationalize the main cultivation techniques. The measurements were carried out every 6 minutes in the space of 24 hours; the tests were repeated during the period April-May 2008. Also outside temperature and relative humidity were recorded by means of a data logger equipped with a thermo hygrometer probe.

The results showed that the mean values of temperature and relative humidity in the part of the greenhouse concerned with the vegetation, differ from the highest part of the structure not involved in the plants. Continuously monitoring these areas, it's possible to appropriately and rationally plan the most important cultivation techniques carrying into effect natural and forced ventilation in order to maintain the optimal microclimatic conditions in the areas directly in contact with the plants.

Keywords: greenhouse, temperature and relative humidity, wireless sensors.

Introduction

Crop production in greenhouses in Sicily has highly increased in the last years from the economical point of view both for the higher profit guaranteed by the advanced or deferred crops and for the growing demand of the market.

The control of the main ambient parameters inside the greenhouse (temperature, relative humidity) plays a very important role in order to optimize the production process [Monarca et al., 2003; Abreu et al., 2004; Carrara et al., 2004; Ottosen et al., 2004].

The systems mostly used in Sicily to record the climate parameters inside the greenhouses are made up of fixed measuring stations realized by cabled sensors applied to some pre-fixed points. On the contrary, the modern wireless systems give the possibility of accurately control the ambient parameters inside the greenhouse with great flexibility due to the facility in positioning the sensors and the possibility of moving them. However, these systems till today are not present in the greenhouse management in Sicily where their introduction should represent a remarkable innovation (Carrara et al., 2007).

The aim of this paper is the optimization of the production process inside the greenhouse through the control of the main ambient parameters with a modern wireless sensor network.

Materials and Methods

The research was carried out in a greenhouse sited in Balestrate (in the province of Palermo, Western Sicily); the crop was courgette (*Lagenaria siceraria*, fam. *Cucurbitaceae*). The greenhouse had a steel frame and an elliptic roof; the walls and the roof were realized with plastic films (PE). The greenhouse has three spans each 8 m wide and 30 m long, north-south oriented. The height of the structure at the centre is 3.90 m; the plants were planted in the soil in rows parallel to the gutters, with a distance of about 1 m between adjacent rows and 1.50 m in the same row. The plants were irrigated around their roots by a drip system.

The plants showed a high density distribution (fig.1) so that their vegetation took up a large part of the greenhouse area, in this way outlining an environment with a specific micro-climate that is very important for plant protection and growth. The precise control of this environment could allow to carry out aimed interventions with remarkable advantages both on the reduced use of the raw materials and on the environment.



Figure 1. Crop inside the greenhouse

Inside the greenhouse a wireless sensor network made up of three node sensors was located. The node sensors, put inside a box, fed by batteries, measured temperature and relative humidity (Sensirion SHT 11, fig.2, measurement range: 0-100% RH, -40-123.8°C temperature); the collected data were downloaded employing the wireless communication in the band ISM with frequency 433 MHz.

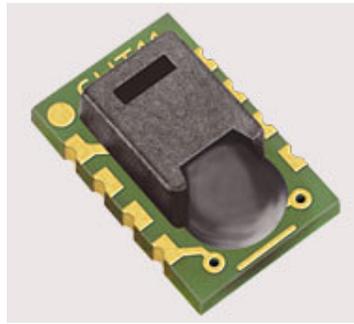


Figure 2. Wireless sensor Sensirion SHT 11.

The sensors (fig.3), called S1, S2, S3, were located vertically in the middle cross section of the greenhouse (fig.4) as follows:

- S1 inside the crop, 1.40 m high from the ground in the middle of the productive area;
- S2 at the top of the crop, 2.10 m from the ground;
- S3 outside the crop, 3.00 m from the ground, in the middle of the area not taken by the vegetation.

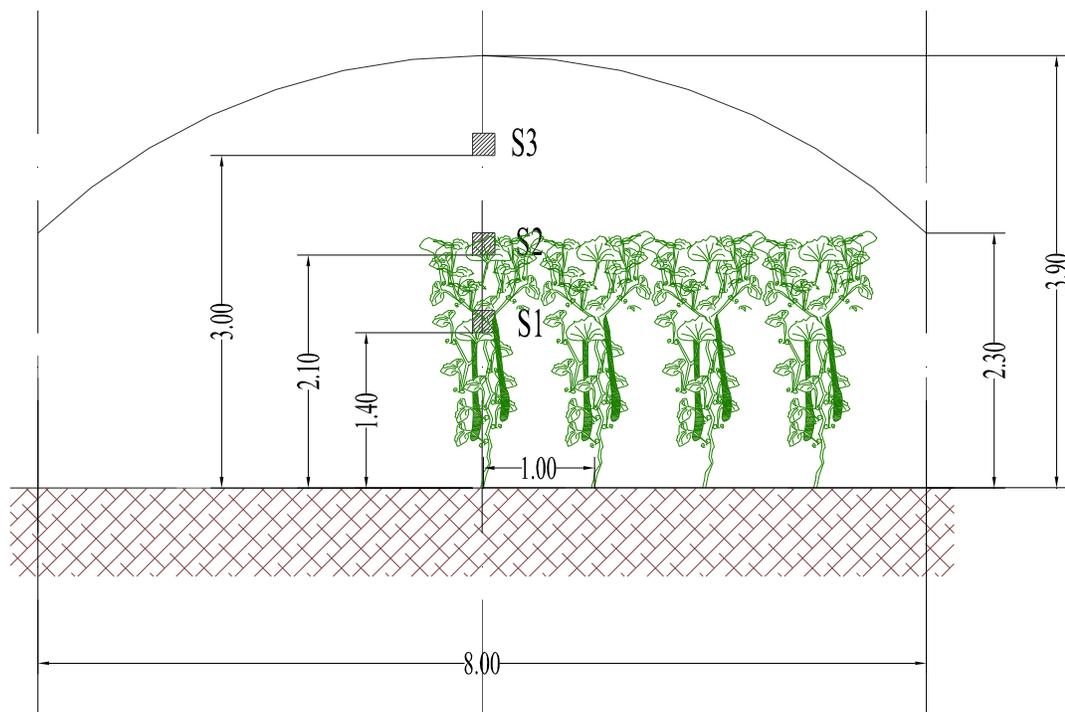


Figure 3. Section of the greenhouse with the sensors



Figure 4. Sensors' position inside the greenhouse

As a consequence, three areas were individuated and monitored one by one inside the greenhouse.

Sensor 1 represents the part interested in the productive area where monitoring the microclimate allows to evaluate the optimum time to perform chemical distribution against the adversities of the fruits.

Sensors 2 represents the area at the end of the vegetation, at the boundary with the high and free part of the structure, where monitoring the microclimate allows to evaluate the vegetative conditions of the plants in order to control the adversities that mainly affect the vegetative part of the plants themselves.

Sensor 3 represents the area located in the highest part of the greenhouse free from the vegetation, where monitoring the microclimate allows to point out the possible critical states involving the two previous areas.

This allows to obtain the microclimate inside the greenhouse and to verify the possible differences of the measured quantities among the three sensors in order to rationalize some of the main operations such as crop protection and irrigation from a sustainable agricultural point of view; the system also allows to rationalize the ventilation inside the greenhouse [Kittas et al., 2002; Romero et al., 2002].

The measurements were carried out every 6 minutes in the space of 24 hours; the tests were repeated during the period April-May 2008.

Also outside temperature and relative humidity were recorded by means of a data logger (Babuc M) equipped with a thermo hygrometer probe (BSU401) and providing real-time measurements every 6 minutes for 24 hours.

Results

Figure 5 shows the values of the temperature measured by the sensors inside and outside the greenhouse during three days representative of the whole monitored period.

It comes out that temperature inside the greenhouse shows a variability among the three areas. In particular, the highest temperature value recorded during the day by the wireless sensors decreases going from sensor 3 to sensor 1: 25°C outside the greenhouse, 29.4 °C in area 1, 33°C in area 2 and 40°C in area 3. The peaks are similar in the three days represented in figure 5.

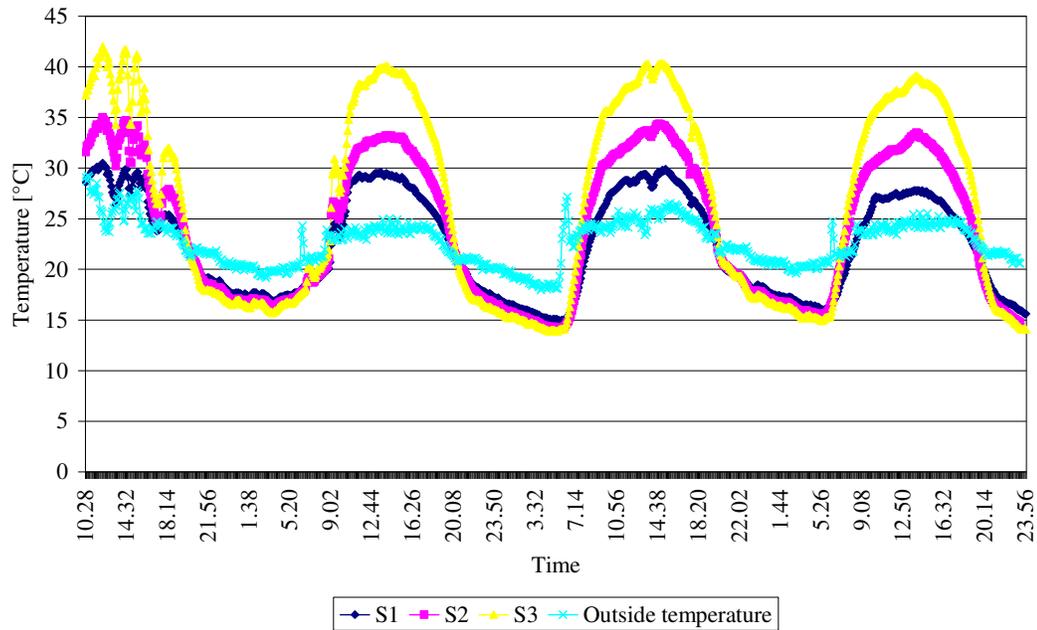


Figure 5. Temperature measured by the sensors

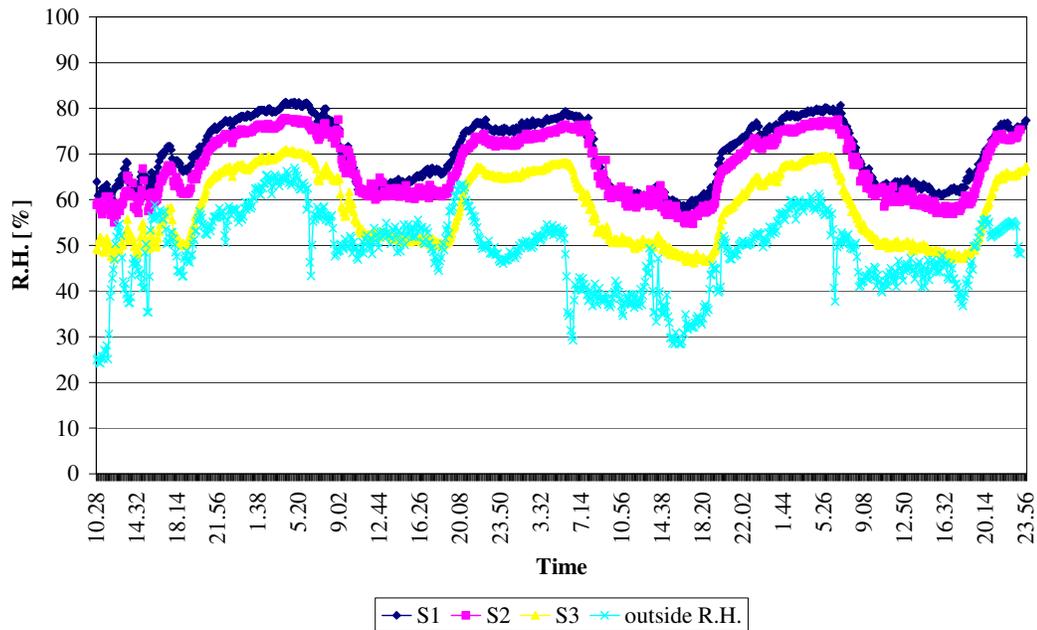


Figure 6. Relative humidity measured by the sensors

From here it comes out that during the day, temperature inside the greenhouse respect to the external one shows a 15% mean increase in area 1, a 24% mean increase in area 2 and a 38% mean increase in area 3. During the night, the mean values of temperature recorded by the three sensors area similar and show a mean 20% decrease respect to the external values.

Figure 6 shows the values of relative humidity measured by the sensors inside and outside the greenhouse during the three days. It emerges that the values recorded by sensors 1 and 2 are very similar; this can be attributed to the intense vegetative activity conditioning the microclimate of the area taken by the plants.

The highest value of relative humidity recorded during the day by the wireless sensors decreases going from sensors 1-2 to sensor 3. The peaks are on average 62% in the area 1-2 and 50% in the area 3, in spite of the mean outside values of relative humidity show a certain variability.

Conclusions

The aim of this study was to monitor the main ambient parameters inside the greenhouse cultivated with courgette, it allowed to obtain interesting information about the distribution of temperature and relative humidity values in different areas directly and indirectly involved in the plants.

The mean values of temperature and relative humidity in the part of the greenhouse concerned both with the productive area and the whole vegetation, show differences with the highest part of the structure not involved in the plants. Continuously monitoring these areas, it's possible to appropriately and rationally plan the most important cultivation techniques carrying into effect natural and forced ventilation in order to maintain the optimal microclimatic conditions in the areas directly in contact with the plants.

In this way it would be possible to reach a rational management of the resources respecting the environment.

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