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Mobile robots in greenhouse cultivation: inspection and treatment of plants

G.M. Acaccia, R.C. Michelini, R.M. Molfino, R.P. Razzoli
PMARLab – Dipartimento di Meccanica e Costruzione delle Macchine
Via Opera Pia 15A
16145 Genova, Italy
E-mail pmar@dimec.unige.it.it

Abstract

The paper presents a service robot for health monitoring and localized chemical, drugs and fertilisers dispensing to plants in greenhouses. The robot and its end-effectors have been conceived and designed specifically oriented to the served environment and tasks. A virtual prototype has been realized.

1 Introduction

The applications of instrumental robotics are spreading every day to cover further domains, as the opportunity of replacing human operators provides effective solutions with return on investment. This is specially important when the duties, that need be performed, are potentially harmful for the safety or the health of the workers, or when more conservative issues are granted by robotics. Heavy chemicals or drugs dispensers, manure or fertilisers spreaders, etc. are activities more and more concerned by the deployment of unmanned options [1]. In the following, some investigations are briefly commented: they were made with the kind support of the CeRSAA (Regional Center of studies and aids in agriculture of Albenga, Savona, Italy), see Figure 1.

Figure 1. The well-known Ligurian basil (courtesy CeRSAA).

Glasshouses, Figure 1, are characterised by small volumes of continuously recycled supporting resources, and have critical epidemic average ratios, enhanced by moisture and lighting continuance (for farming effectiveness) favouring the spread of biotic agents.

Greenhouses are translucent glass or plastic constructions for hastening the growth of plants. The distribution of plants inside greenhouses usually consists of an alternation of double rows of plants and narrow corridors for human operation and walkway. This kind of agricultural technique is massively used for intensive production of horticultural products in regions with adverse natural climatic conditions, since it allows a more effective use of water and daylight.

The favourable atmosphere created inside greenhouses for plant growth causes pests and undesirable organisms to thrive as well, making necessary the use of pesticides and other chemical products that must be sprayed directly on the plants [2].

Today solutions massively depend on heavy chemicals, plentifully distributed at given time intervals, making the greenhouse indoors highly toxic, with operator health shocks and forbidden re-entry long lasting delays.

Recent studies reported confirmation that spraying operations have hazardous effects on the health of knapsack sprayer human operators, who are specially exposed when working inside greenhouses, in conditions of high temperature and poor ventilation.

Therefore, the automation of spraying, as well as other greenhouse operations like monitoring and control of environmental conditions, harvest support, plant inspection, and artificial pollination, has a dramatic social and economical impact.

In the recent past some few robotic solutions for greenhouses automation have been proposed.

The project AURORA [3] suggested a robust and low cost robot for greenhouse operations, able to autonomously navigate in different kinds of greenhouses. The robotic system is tele-autonomous: in the sense that the remote supervision of autonomous tasks and shared human control are both viable. For the remote tele-operation station a video camera has also been included, so that images and sonar data are combined in a friendly operator interface.

Another project for greenhouses automation is AGROBOT [4], [5], a mobile robot with a stereoscopic vision system and a six degree of freedom arm for the greenhouse cultivation of tomatoes. The head permits complete visibility of the overall area.

A modular, easy to assemble, greenhouse suitable for incorporation into a lunar settlement has been proposed [6]. A semiautonomous robot acts as a telefactor system for crop harvesting. It is supported by twin tracks suspended from the ceiling.

Other few similar projects have been funded in Japan [7], [8].

Mainly automation charges considered within this project, and discussed with the experts of CeRSAA , are:

- monitoring the growing health state;
- picking up samples of leaves from the plants suspected to be sick;
- fetching these samples to the laboratory;
- performing the spraying operations locally towards the plants acknowledged as sick;
- monitoring of the harmful chemical residuals within the greenhouse;
- assessing the re-entry safe time, after each spraying operation.

One of the main robot task is to analyse the plant to acknowledge its health state. To perform this function the symptoms evinced by the ill plants have to be considered and their effective recognition through sensorial devices has to be verified. All the pathogenic agents that infest the plants change the look of the plants in different (more or less perceptible) ways. For this reason the robot vision system and algorithms are designed and tuned to take into account the great variety of symptomatologies affecting the green of the leaves with evident rottenness or with spots nearly undetectable by the human eye.

Studies performed in USA introduced a new method to analyse the plant health state, based on the light reflected when it is illuminated by rays of given wave length. This method should simplify the control system but, unfortunately, it is not applicable to different kind of cultivation.

These difficulties suggested to use the service robot not as a medical robot able to see the symptom, understand the health state and provide the treatment but as a robot courier able to draw a leaf from the plants deemed ill and to take it to the analysis laboratory.

When some plants are acknowledged as sick, the service robot provides the treatment locally, basing on the diagnoses made by the laboratory analysts, and verifies the correct functioning of the greenhouse automation system that assures the right environmental conditions, irrigation and feeding solution recipe, which, if wrong, could have initiated the plant illness. It is important to act as soon as possible to avoid a greater damage involves a larger zone in the greenhouse. For this aim, the robot is equipped with probes for ground humidity and feeding solution pH measurements.

The preventive treatment of greenhouses plants is usually performed by spraying operations, which concern the entire cultivation, regularly repeated and consuming a lot of chemical products and water. A more cost-effective and sustainable method can be used employing the robot to supply the single ill plants with the chemical curative solution nebulised through the use of suitable ceramic nozzles.

2 The Robot Design

The greenhouses are considered as structured environments where objects populating the area are carefully organized and leave very narrow space to the greenhouse service assistant.

2.1 The mobile support

The robot locomotion mobility is performed on a plane and can be obtained through a narrow mobile platform or by track rails suitably joined to the greenhouse ceiling structure. Both the solutions have been examined and compared.

Mobile platform

The mobile platform is more flexible and can serve different close greenhouses without any further structure. But stability problem during the work may arise when the arm is extended, due to the narrowness of the base. It was decided to choose a mobile platform from the market, which has to be:

- of narrow dimensions to be dexterous when moving between rows and stalls;
- robust but lightweight to avoid sinking into the soft ground (mainly in condition of high humidity);
- agile on irregular ground and able to overtake obstacles such as pipes and hoses;
- stable, because often the arm works as a cantilever.

Another problem is due to energy source; to make the robot as free as possible in its movements, the adoption of on-board batteries is suggested, but this limits the autonomy range and calls for proper human intervention to replace drained batteries.

Suspended solution

The suspended solution is more dedicated than previous one and requires to add rails to the ceiling of the greenhouse and proper areas linking it to the laboratory for the analysis of collected samples of plants, see Figure 2. It allows to the robot the reach plants from above, leaving free space and access at the ground level for humans [11].

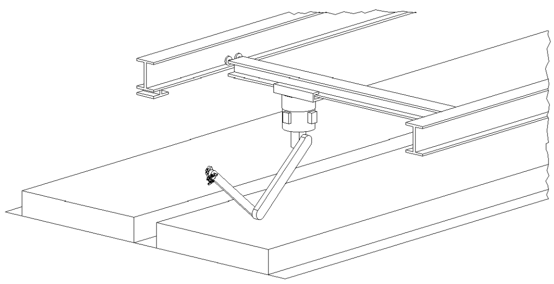


Figure 2. The robot support structure.

A drawback of the suspended arrangement is the need of cables for energy supplying, and these, together with the built-up of railing, makes quite hard to devise an effective method for the robot passing from the greenhouse to the laboratory.

2.2 The arm

The arm design takes into account the two different navigation solutions of which it can be equipped.

The attention has been given to the operations directly performed on the individual plant. They require time and a robot that is devoted to continuously serve the greenhouse. According to the basic specifications, taking into account the supporting device mobility, the minimum number of degree of freedom is 3. A serial chain architecture R_z R_y R_y has been chosen.

The arm end must reach all the plants, both at the ground and over the stalls and the storage on which it will orderly keep the leaves samples to analyse and/or the phytodrugs.

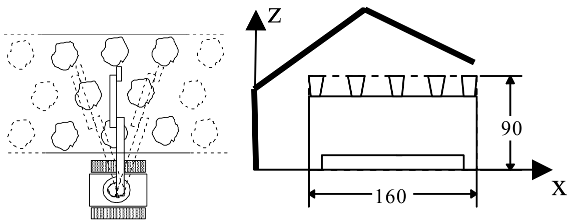


Figure 3. The relative position of the robot mobile platform and the plants (lengths in cm).

To select the robot size, the following points are considered:

- the robot workspace, defined by the distribution of the plants;
- the possible obstacles positions;
- the member lengths have to be kept as short as possible for economical and structural reasons;
- the forearm has to reach the working point with an angle suitable to avoid touching the plants below.

The workspace analysis has been performed by the Pro/ENGINEERING sketcher to easily consider the possible obstacles, the main dimensions have been defined according to geometry consideration, see Figure 4, where E_2 represents the position of the joint between members 1 and 2. S_1 and S_2 are the workspace extreme points at the stall height h and I_1, I_2 are the extreme points at the ground; b is the stall width.

The resulting lengths of the first three members are: $l_1 = 1$ m, $l_2 = 1.25$ m and $l_3 = 1.10$ m.

The arm design has been performed by the parametric Pro/ENGINEER CAD modeller and, with the aim to improve the static stability, the motors are relocated: the first one in the base and the other two in the first member, before the shoulder. Figure 5 shows the motion transmission mechanisms and Figure 6 the arrangement of the first member actuation into the robot base.

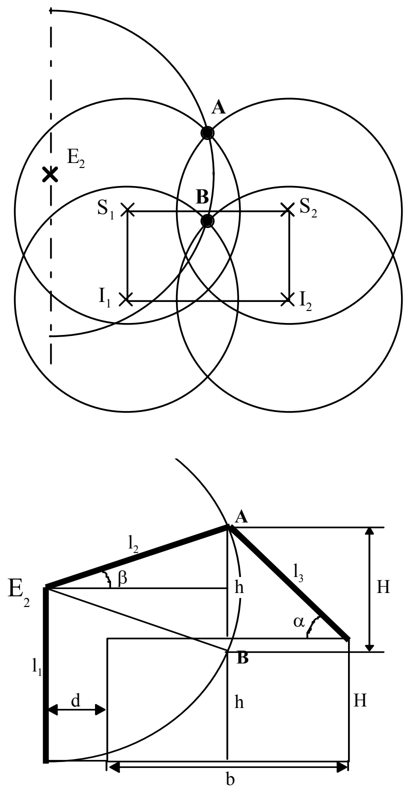


Figure 4. The graphic method used for the arm members sizing (sketches not scaled).

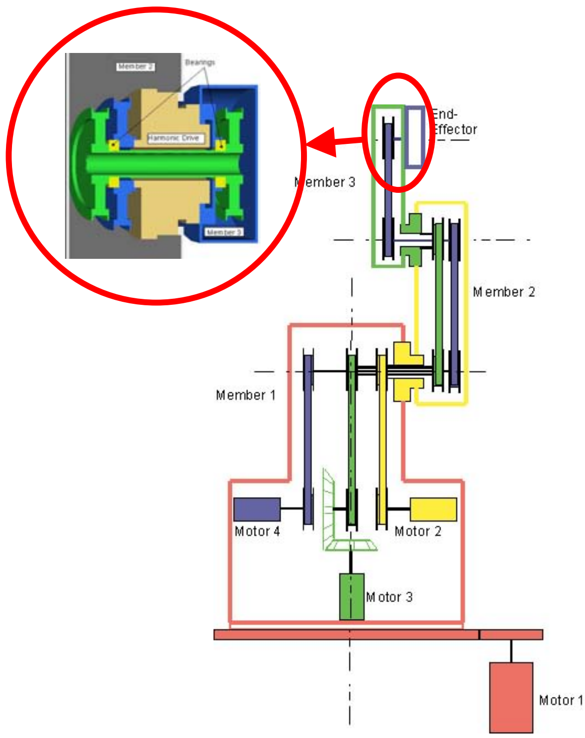


Figure 5. The scheme of motion transmission mechanisms.

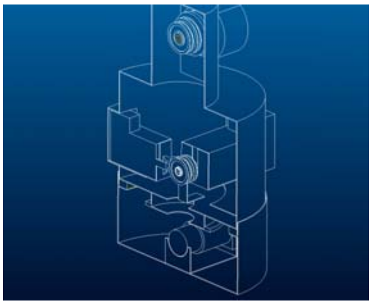
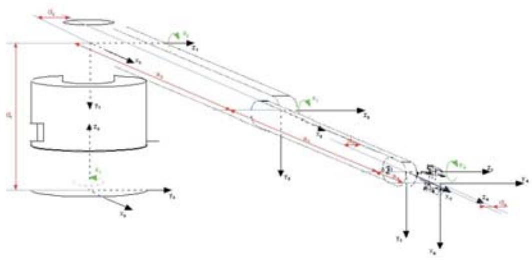


Figure 6. Broken view of base transmission.

Lightweight toothed belt mechanisms together with hollow shaft reducers are used. All the power and service (spraying, data, ...) cables are hosted inside the members so avoiding damaging by chemical dangerous agents dispersed in the environment.
The arm DH parameters are shown in Figure 7; the direct and inverse kinematics algorithm are straightforward.



membro	α_i	a_i *[mm]*	d_i *[mm]*	θ_i
1	*-90°*	*0*	*1000*	θ_1
2	*0°*	*1250*	*125*	θ_2
3	*0°*	*1100*	*-70*	θ_3
4	*90°*	*150*	*65*	θ_4

Figure 7. The kinematics parameters.

Avional and polyammide materials have been selected for the arm structure, because they are high lightweigth, and, above all, are resistant to chemical agents.

2.3 The end effector

To perform the gardener-robot tasks, the end-effector needs a scissors gripper and a spraying device. Besides, the robot requests stereoscopic vision to be able to single out a sick plant, mainly through its colour change, and to pick leaves samples. For this purpose, a head supporting two cameras is mounted at the end of the arm, in backward position respect to the gripper, so avoiding the contact between the head and the plants.
To synchronise head and hand, their shafts are driven by the same motor; it actuates the unique degree of freedom of the wrist.
The arrangement of the system eyes-hand is shown in Figure 8. This arrangement was preferred to the cameras mounting on the vehicle structure because it allows the vision is not obstructed by the arm itself and by other objects in the greenhouse.

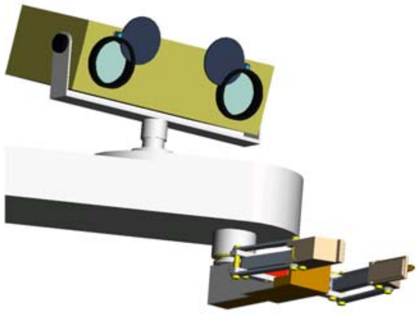


Figure 8. The eyes-hand system.

To protect the cameras from dust and spray the cameras are enclosed within a plastic box, called head. A simple mechanism agrees to to open/close some kind of (eye)lashes made by hard plastic disks and housed into rubber rings, allowing vision only if cameras are activated. The disks are simultaneously moved by a small stepper motor and gear reducer-transmission housed in the head box.

The head support permits the yaw, but this mobility, useful only for off-line cameras registration, is manual.

The operation of leaf picking is a critical task and, if not properly executed, could damage the plant. The picking is performed in two phases miming the manual picking: first, the leaf is blocked between the fingers, then, it is cut. To accomplish these tasks the gripper, Figure 9, presents two fingers: the lower is simple and offer a plane surface for the leaf; the upper is equipped with a plate, that can vertically slide pushing a spring, and with a U shaped knife, see Figure 10.

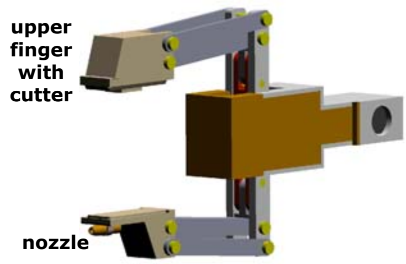


Figure 9. The gripper.

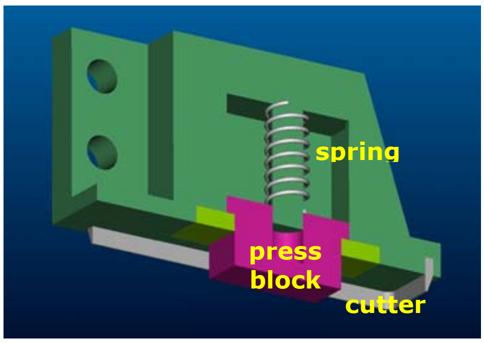


Figure 10. The upper finger: it is half cut to show the press block and the U shaped knife.

A parallelogram mechanism is used to in parallel open and close the fingers.

First the leaf is grasped and sized between the lower finger and the upper plate, then it is cut and the gripper stores it into a small drawer of the on-board buffer, memorizing the concerned plant coordinates.
The adopted gripper mechanism is sketched in Figure 11: a rack actuated by a pneumatic cylinder drives two specifically shaped gears pivoted to the frame and constrained to a phalanx by a pin sliding into a phalanx slot.

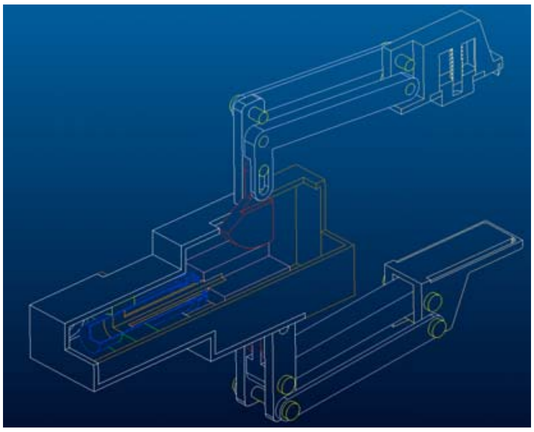


Figure 11. A model of the gripper: in the upper portion the actuation mechanism is evident: a rack engages with a toothed sector driving a side of the parallelogram.

The phalanx itself, pivoting to the frame induces the gripper opening and closing.
The static analysis of the gripper mechanism, see the sketch in Figure 12, considering the closing force orthogonal to the closing arm, provides the following rate between the closing and actuation forces:

$$F_r = \frac{b_3 x}{b_2 b_1 \sin\theta} F_a$$

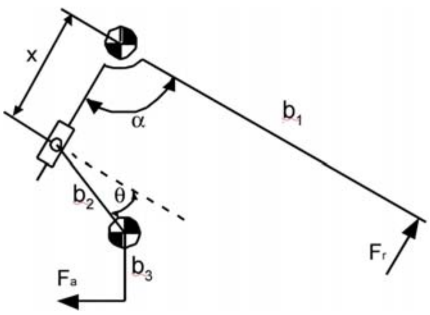


Figure 12. Gripper mechanism functional sketch.

The choice of the motor and the dimensioning of the gripper has been made by optimising the gear ratio so that the maximum force is exerted at the closing point while when the gripper is open a low force is preferable, because resistant forces are not present and the moving masses are limited. In addition, the overall size of the gripper has been limited as much as possible, having as a constraint the workspace needed to match the usual shape and dimensions of a leaf.

The lower finger of the gripper is equipped with a sprayer, Figure 9, selected from the market: it works at a pressure of 6 bar and has small dimensions; a rubber pipe takes the fluid to it from a steel tank housed in the mobile base. An electromagnetic valve allows to open and close the fluid feeding.

To define and verify the arm actuation a simulation campaign was programmed while the arm dynamic model performed different tasks. A critical examined task refers to Figure 13 and some results are shown in Figure 14.

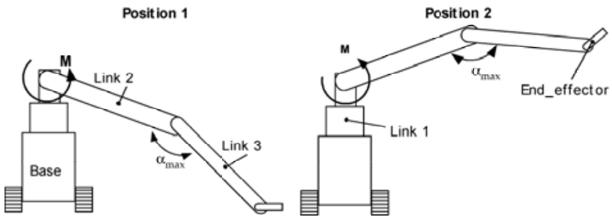


Figure 13. The initial and final position of the reference task.

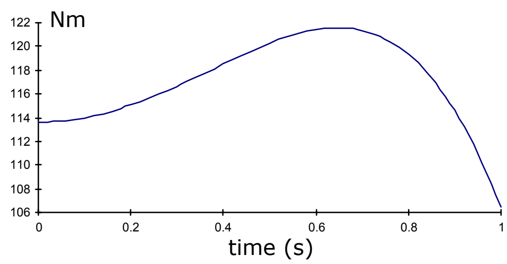


Figure 14. The torque applied to the shoulder to keep an acceleration of 2 rad/s^2.

2.4 The control system

The proposed greenhouses gardener is a robot continuously dedicated to the plants health and the environmental condition control inside the greenhouse.

It is trained to know different plants illness symptoms but it does not have the responsibility of diagnosis decision. In case of a, also minimum, doubt, the robot gathers a leaf sample and call for a laboratory analysis.

Navigation is easy because it starts when the greenhouse is unmanned and no mobile obstacles are present.

Navigation for inspection: the robot advances on pre-programmed paths at very slow velocity and observes the plants: if it sees some anomalies it stops the navigation task and begins a leaf picking task moving the base in front of the selected plant and performing the picking with vision served gripper. When the on-board leaves buffer is full or the task time expires, the robot goes to the analysis laboratory where expert people perform the test analyses.

Navigation for treatment: from the analysis laboratory a point to point navigation is programmed assigning to each ill plant the local treatment. The navigation from one point to the next is done at high velocity while the plant treatment is carefully performed through the end effector facilities. To each treatment typology is assigned a macro-task that can be recalled by the main task.

Analogously, the other robot tasks are defined for the ground and environment monitoring.

In effect, the robot is not intelligent but behaves as a serious, secure, untiring and entrusted server that refers to expert humans for the high level tasks and the decision making.

3 Conclusions

Intensive agriculture shall quite soon require investments and innovations to increase productivity and to protect natural resources for the coming generations.

The problems dealt with are limited to applications for phytopatologies treatments, specifically aiming at individual diagnostics and disease extirpation, in order to avoid the generalised spraying of poisonous stuffs.

In the Sixth Framework Programme, strong attention is posed to food related activities, with the aim to envisage efficient procedures and techniques for betterment of plants growth, while using eco-compatible treatments and drugs.

This general trend is particularly evident for the truck farming with glasshouse support and robotics will supply the instrumental aids to grant effectiveness, on condition that the fixturing rigs provide low-price solutions with task-driven equipment.

Moreover, the illustrated solution may be usefully employed for flowers, or other vegetables cultivation, so widening the spectrum of likely opportunities.

Resort to Digital Mock-Ups allowed to perform dynamic and structural analyses in the early stages of the design process. Simulation campaigns assessed the fitting of the device, in order to grant safe and reliable tasks progression.

A life-cycle approach has been adopted for evaluating fall-offs during design, service, maintenance, dismantling phases while a mechatronic thinking of the outfit aided to carry on a balanced solution among the several technical aspects, covering mechanics, control, sensing and informatics.

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