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ON THE AUTOMATION OF PLANT REPRODUCTION BY CUTTINGS

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ABSTRACT

The tedious and repetitive manual work is one of the activities in which we try to facilitate the operator through the use of assistive devices or through automation, which can replace it in the most repetitive operations. The reproduction of plants by cuttings is one of the most widespread techniques for obtaining new plants and it is an activity carried out in manual way also in manufacturing companies that produce young plants. Automation is also important in these applications for safety purposes, because repetitive and tedious activities tend to keep the operator's attention low and therefore increase the likelihood of accidents. This paper presents the development of a prototype to automate some stages of the reproduction of young plants by cuttings. Preliminary analyses to measure some characteristics of the selected ornamental plants, the prototype design work and the experimentation phase, both in the laboratory and in the field, which gave satisfactory results are illustrated.

Key words: plant reproduction, cutting, automation.

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1. INTRODUCTION

The propagation of plants is the phenomenon that allows to produce, from a specimen of origin, more specimens that may have similar characteristics or different from the original ones. The propagation of plants can take place essentially in two ways: by seed (gamica or sexual) or by plant parts (agamic or asexual, also called vegetative).

In the first case the seed is used; in the other there are several ways: the division of the tufts, the layering, the grafting, the spread and the cutting. In the propagation by cuttings, which is the technique of interest for this research, we obtain, from a single plant, many seedlings called cuttings, separating and planting parts of the original plant, for example material obtained by pruning. Generally the plants obtained by cuttings are identical to the mother plant, even though different kinds of cuttings can be obtained from every single plant.

The cutting is a piece of a parent branch that, once inserted into the ground, develops roots creating a new plant similar to the parent. Many ornamental plants can be reproduced by cuttings: Ligustrum, Photinia, Viburnum, Callistemon, Spiraea, Tamarix, etc. There are many differences among these ornamental plants for the application of this technique (type of cuttings, preparation of plants, etc.), also due to the different morphology and characteristics of each plant. The propagation process by cuttings in a company laboratory follows these five steps:

- The cut of the mother plant. Young and vigorous parent plants are used to obtain branches, possibly also secondary branches, to be used for the production of cuttings. The parent branches must be completely turgid. They must be irrigated to avoid water loss, and little time should elapse between cutting the branches and arranging the cutting into the substrate.
- The cuttings of the branch. The parent branches are cut to produce cuttings. Each cut must include at least one leaf node, at the lower end, for the production of the new roots. The cuttings are collected together and kept wet. If necessary, they must be rehydrated by immersing them in water.
- The removal of the leaves. Each cut must be worked to remove the leaves from the stem in the basal part of the cut. This operation is important to prevent the leaves from being inserted into the substrate and causing problems to the new plant.
- Dispense the plant hormone. It consists in the immersion of the basal part of the cut in a vegetable compound to favor and stimulate the formation of the roots.
- Inserting cuttings into the substrate. Each cut must be inserted into an alveolus usually placed in a tray with several alveoli. The normal trays in companies for the production of ornamental plants mentioned are formed from 120 to 160 distinct alveoli. A substrate is used for cells to promote rooting and prevent root breakage.

These steps are usually performed in laboratories to reproduce plants for sale. The work is all done by hand and is very repetitive and alienating. Today, the production of young plants has become an industrial activity with increasing production volumes, strong price competition and a market for the sale of not only regional but national products and, for some ornamental species, international. From this consideration comes the interest of operators in order to develop or acquire production technologies that will reduce production costs and increase the company's competitiveness on the national and international market. It is advisable to consider that the productivity of an operator experienced in carrying out operations of cutting the twigs from seedlings, that perform the function of the parent branch, is about 300 cuttings per hour per single operator. This figure was measured by an important survey carried out in the field by the authors through some companies operating in the sector.

In the scientific community there has been little interest in reproducing plants by cuttings with automatic devices and/or systems, despite the big developments that have occurred in the non-traditional applications of robotics [1], even with applications in agriculture for example on flower and plant harvesting systems [2-4], and despite the aging population push for the introduction of robotic technologies in order to alleviate the work of the operator. There are however scientific works that refer to the reproduction by cuttings of plants that are used as biofuel [5,6], others that concern plants difficult to reproduce by cutting [7,8] as well as works or books that deal with reproduction of plants in general [9] and that for cuttings in particular [10-12]. However, automatic collection systems are available in the development phase [13], for the cutting of the chrysanthemum [14,15] and for other greenhouse works: irrigation, herbicide spreading and movement of potted pallets, etc. [16].

This paper presents a new system to automate the process of cutting branches of ornamental plants to produce cuttings for their vegetative reproduction. Starting from the manual insertion of a stem of the parent branch, without secondary branches, the automatic machine moves the branch, to identify the leaf node, to remove the leaves from its basal part and finally to the cutting making it available at subsequent operations until insertion into the alveolus. This research on the automatic plant reproduction system through cuttings is in progress with the prospect of automating the feeding in the machine of the branches and with the integration in the presented prototype of the grip, of the insertion into the solution with hormones and of the positioning of the cutting in alveolus. Another perspective on which one is working is to conceive a self-guided mobile unit that can take the branches cut after pruning, the transport and loading of the stems of the branches in the prototype presented, using for example a navigation system based on the 3D scanner technology [17,18].

2. PRELIMINARY ACTIVITIES

Ornamental plants are very common in Europe and should be classified in relation to some characteristics that affect the automation to be realized: plants without leaves, such as Forsithia Viridissima, plants with leaves of medium size but in small numbers, such as the plants of Photinia Red Robin, with many medium-sized leaves, such as the Viburnum Tinus Lucidum, plants with many small leaves, such as the Bruxus Sempervirens, and plants with many small leaves and thorns, such as the Piracantha Moave.

a) b) c) d) e)

Figure 1 Parent branches and cuttings of: a) Viburnum Lucidum (large leaves and foliage); b) Bruxus Sempervirens (small leaves and without thorn); c) Piracantha Moave (small leaves and thorns); d) Photinia Red Robin (large leaves and foliage); e) Forsithia Viridissima (without leaves)

In Figure 1 the branches and cuttings of these ornamental plants are shown. In this paper, the focus is on plants with medium-sized leaves, so that the extension of the results to plants with small leaves or leaves should not be particularly difficult.

To cut the cuttings requires particular attention, as it must take place without fraying the edges. A simple set-up was then carried out, which uses a commercial shear, to study the problems of cutting branches and to measure shear forces, so as to obtain important indications for the design of the automatic system, of some ornamental plants: Robinia red robin, Viburnum tinus lucidum, Forsithia viridissima and Bruxus sempervirens.

Samples of branches with different diameters were used and the tests were performed with 2 different cutting modes: branch in contact with a cutting edge and branch placed between the two cutting edges without any contact. Figure 2 shows the set-up.

Figure 2 Set-up used for the measurement of the cutting force with a detail of a branch cut without fraying

The criteria adopted to classify the results of the tests are the following: good cut (G), if the cut of the branch was complete and without fraying; not good cut (NG), if the cut is complete, but there are fringes in the cutting sections; bad cut (B), if the cut was not complete. The test campaign allowed to obtain useful results for the design of the automatic system, see Table 1. In particular, cutting with the branch in contact with a blade leads to worse results than the non-contact branch and pneumatic cutting force values greater than 353 N allow to always obtain a cut without fraying. The value of 4 mm was chosen as the maximum diameter of the parent branch that the automatic system can process, and therefore the design cutting force was set equal to 235 N.

Table 2 shows other features of interest of the branches of Photinia and Viburnum, which are the species selected for the automation system. They show a high degree of flexibility, such that if they are bent and/or flexed they do not break. The leaves and the leaf-stalks have a very high maximum arrow value; they only break if pulled and/or torn and can twist on the branch without breaking.

On the other hand, the branch, compared to the leaves and the leaf-stalks, has a greater stiffness, therefore a reduced flexibility. This last aspect represents an advantage in the design of the new automatic system, in that, in order to identify the node and cut it on the branch, it is necessary to move and orient the leaves and the leaf-stalks. In order to accomplish this movement, it is necessary to flex and bend the leaves with respect to the branch.

Table 1 Results obtained from cutting tests of branches of ornamental plants: Photinia Red Robin, Viburnum Tinus Lucidum, Bruxus Sempervirens, Forsithia Viridissima

			Photinia Red Robin				
pneumatic cutting force			176 N	235 N	294 N	353 N	411 N
Non contact/In contact with a cutting edge	diameter	6,5 mm	B/B	B/B	G/NG	G/G	G/G
		5,5 mm	B/B	B/B	G/G	G/G	G/G
		4,5 mm	B/B	NG/NG	G/G	G/G	G/G

			Viburnum Tinus Lucidum				
pneumatic cutting force			176 N	235 N	294 N	353 N	411 N
Non contact/In contact with a cutting edge	diameter	6 mm	B/B	B/B	G/NG	G/G	G/G
		4,5 mm	B/B	G/G	G/G	G/G	G/G
		3,5 mm	NG/B	G/G	G/G	G/G	G/G

			Bruxus Sempervirens				
pneumatic cutting force			176 N	235 N	294 N	353 N	411 N
Non contact/In contact with a cutting edge	diameter	2,5 mm	B/B	G/G	G/G	G/G	G/G
		2 mm	NG/NG	G/G	G/G	G/G	G/G
		1,5 mm	G/G	G/G	G/G	G/G	G/G

			Forsithia Viridissima				
pneumatic cutting force			59 N	118 N	176 N	235 N	294 N
Non contact/In contact with a cutting edge	diameter	5 mm	B/B	NG/B	G/NG	G/G	G/G
		4,5 mm	B/B	G/NG	G/G	G/G	G/G
		4 mm	B/B	G/G	G/G	G/G	G/G

Table 2 Measured characteristics of the parent branches of the plants selected

Characteristics	Photinia Red Robin	Viburnum Tinus Lucidum
minimum - maximum diameter of the stem of the branch	4 - 5 mm	3 - 6 mm
average length of the branch	~ 500 mm	~ 400 mm
minimum - maximum distance from the axis of the parent branch to the apex of the leaf	55 - 105 mm	50 - 140 mm
minimum - maximum leaf width	35 - 50 mm	40 - 55 mm
length of the leaf-stalk	~ 10 mm	~ 20 mm
average distance between two successive nodes on the branch	35 ÷ 40 mm	70 ÷ 80 mm
opening angle of the leaf to the leaf-stalk attachment	≤ 60°	≤ 60°
curvature of the branches	small or no curvature	small
consistency of the branches	very high	medium
flexibility of the branches	low	medium
consistency of the leaf and leaf-stalk	very low	very low
flexibility of the leaf and leaf-stalk	very high	very high
resistance of the leaf to pulling or tearing	small	small

3. THE DESIGN OF THE PROTOTYPE

The automatic system for the reproduction of young plants by cutting, for the ornamental plants on which it was chosen to operate, Photinia Red Robin and Viburnum Tinum Lucidum, consists of 5 phases that have been defined starting from the careful observation of the operative steps followed by companies in the manual production.

The first step is represented by cutting the parent plant to obtain the parent branch. This operation is carried out in the company by expert operators who are able to quickly adapt to the differences in size of the branch, consistency, shape, and the presence and extension of secondary branches. The complexity of this operation is therefore high and it was considered appropriate to exclude it from the project thinking of developing a machine that must receive in a defined location the parent branch from which to start the production of cuttings. The limit in the design of the machine, which is activated only with the branch inserted manually by the operator, can easily be overcome in the future by designing an automatic feeder of parent branches. This feeding machine does not present high technical difficulties but in any case it will require that the parent branches, which will be loaded at the input of the automatic feeder, are manually prepared. The second and third steps, related respectively to the cutting of the stem and the removal of the basal leaves, are operations that the machine will have to carry out. The fourth and fifth steps, respectively hormone administration and insertion into the substrate of the cutting, are not foreseen in the present project. This choice has matured from the belief that it is easy to think of a robot at the exit of the machine to carry out the operation of 1) Taking the cuttings, 2) Immersion in the solution of growth hormones, 3) Insertion in alveolus.

So the system for reproducing ornamental plants by cutting that we want to develop must: 1. start the operations with the parent branch inserted in an assigned position of the machine; 2. handle the branch in the machine with delicacy for the foliar apparatus present; 3. identify the presence of the nodes; 4. remove the leaves from the basal part and then perform the cutting of the cutting; 5. take the cutting just produced and take it to a position where it can be taken by an external robot/manipulator for the following steps.

The design of the machine involved the development of several units that must be appropriately developed and integrated: a unit for moving the parent branch, a unit for moving the leaves, a sensorized unit for locating the nodes, a cutting unit of the branch and a leaf removal unit. Figure 3 shows the procedure for the automatic system of production of plants by cuttings.

4. THE PROTOTYPE MANUFACTURED

The concept of the movement system of the parent branch is shown in the drawing of Figure 4, together with the leaves removal procedure. In the same figure, the sensors for detecting the nodes and the leaves separation system are also shown.

The automatic system for the creation of cuttings was designed and implemented by integrating four units. The device for the selection of the leaves is formed by 3 thin sheets in the shape of an isosceles triangle (selection plates), with the upper vertices near and arranged at 120°, with respect to the center of a horizontal circle where the parent branch that is moved vertically along its axis is placed.

Each of these sheets has a degree of passive radial freedom, to have an area of passage of the branch that adapts to the diametral dimension of the branch.

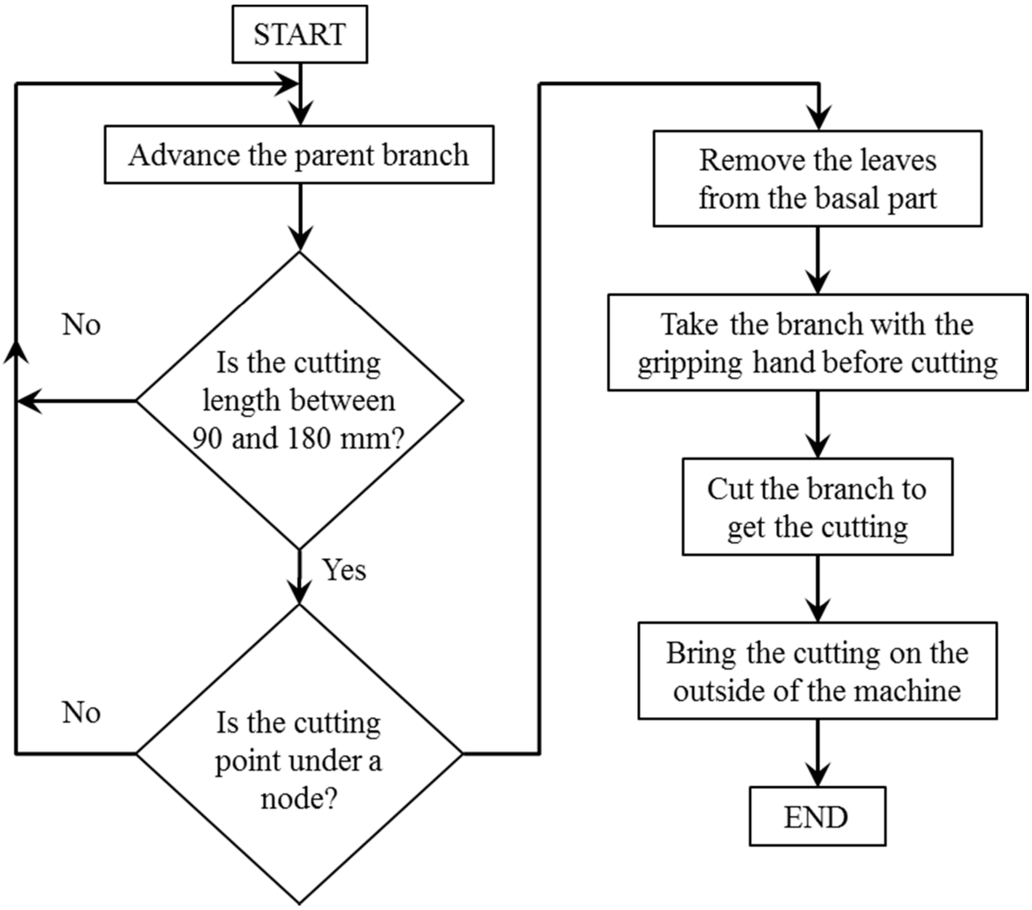

Figure 3. Flowchart of the process that will follow the prototype

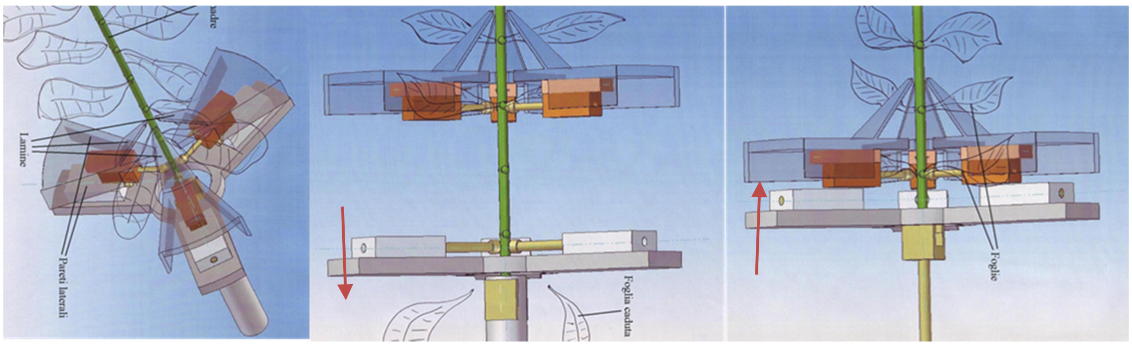

Figure 4 Concepts of the system: the motion of the branch, image on the left; the defoliation, image in the center; grasping of branch for a new cutting image on the right

During the motion of the branch, which is dragged downwards, the leaves are channeled into one of the 3 radial sectors between the triangular sheets. The cutting unit has only 2 working positions thanks to a linear slide: rest position and branch cutting position. The cutting blades are made from parts of commercial pruning shears, to easily obtain excellent cutting quality. The structure of the cutting unit was realized by 3D printing, adopted in several scientific sectors [19]. In Figure 5 the cutting unit is shown both in the design drawing and in the realization on the prototype.

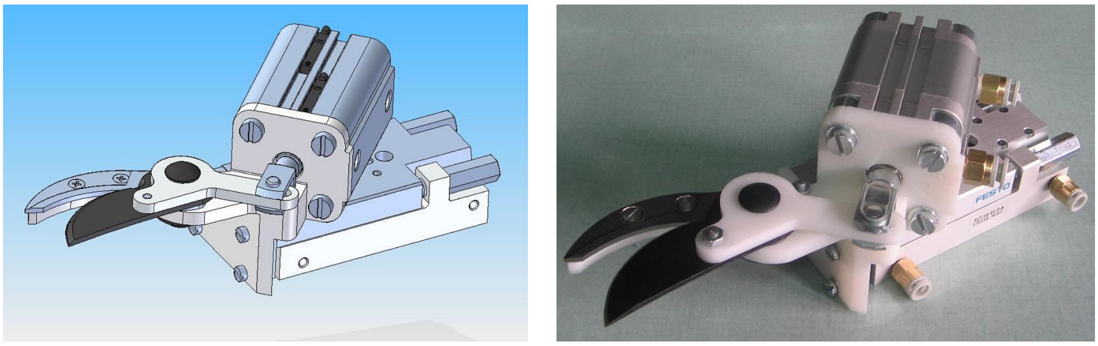

Figure 5 Isometric view and prototype of the branch cutting unit

Below the cutting unit, close to the knife, contact sensors of the leaf nodes, one for each leaf selection plate, are placed. When the parent branch moves, the leaf nodes come in contact with the sensors. The sensors, whisker types, have been realized in the laboratory by the authors and experimentally tested. The movement unit of the parent branch consists of a vertical pneumatic slide and a three-fingers radial pneumatic gripper. The latter grasps the parent branch and drags it downwards. The gripper is shown in Figure 6.

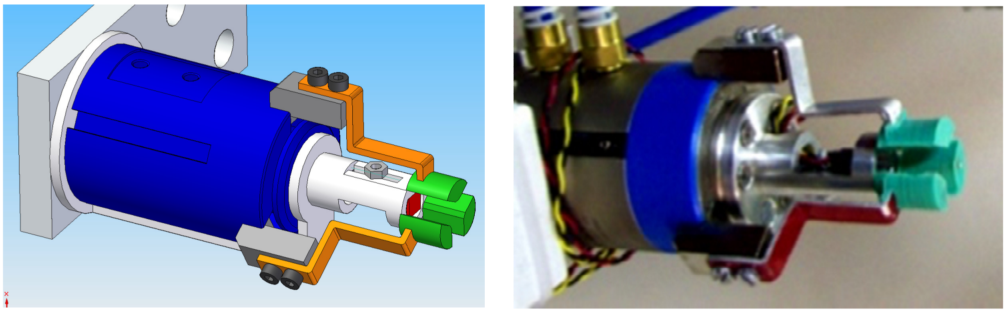

Figure 6 Design and prototype of the 3-fingers gripper for the movement of the branch

An optoelectronic sensor is mounted in this gripper to detect the presence of the parent branch. The defoliation of the branch occurs by a unit made of two sliders, one for vertical and one for horizontal movement, supporting a three-finger gripper, shown in Figure 7. The open gripper horizontally approaches the branch; then, it closes and the defoliation occurs by the downward movement.

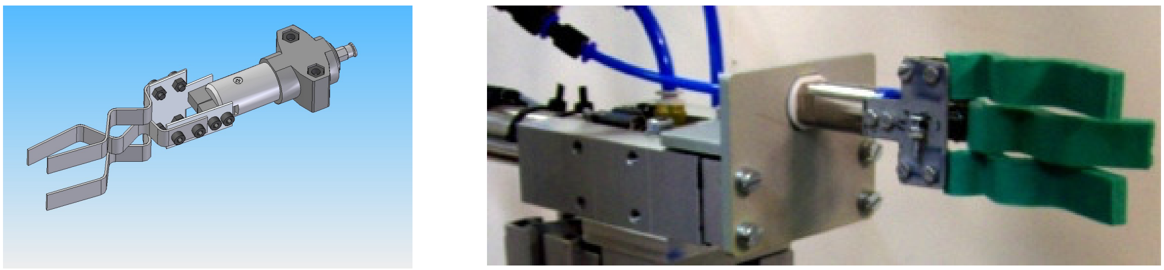

Figure 7 Draft and prototype of the 3-fingers gripper for the defoliation

The entire unit is mounted on a 180° rotating table to transfer the cutting out of the working area of the automatic machine in order to be available for an external robot/manipulator.

4.1 The control system

The machine management and control system is loaded on a Siemens S7-200 PLC and command buttons and indicators areplaced on a panel. The cycle was first formalized in the SFC (Sequential Functional Chart) language and the total number of the work steps is equal to 28. Then, it was translated into the KOP language and stored into the PLC. The software reads 27 input signals between sensors and buttons, all powered at 24Vdc. Six buttons are "on/off", "single/continuous operation cycle", "start", "stop", "step-by-step operation cycle" and "home position". As for the sensors, 3 are the contact sensors used to detect the leaf nodes, a sensor detects the insertion of the branch, while there are 17 end-of-stroke signals of cylinders, linear slides and grippers. The outputs are 18 and include 16 outputs for controlling 8 solenoid valves, one for a monostable solenoid valve and one for the warning light.

4.2 THE EXPERIMENTAL TESTS

The experimentation was conducted with three test campaigns. In laboratory experimental tests, 3 different ornamental species were used: Photinia Red Robin, Viburnum Lucidum and Ligustrum, which has the characteristics of Photinia but is available for a long time of the year. The parent branches have been selected so as to have branches with a rectilinear development, i.e. slightly accentuated curvature.

The first two test campaigns were conducted in the laboratory while the third was conducted in a greenhouse and the prototype was connected to a manipulator for taking the cutting. The first test campaign was aimed at validating the constructive solutions adopted for the individual units. The leaf selection unit behaved very well in the manual tests that confirmed the correct movement of the leaves in contact with the 3 triangular plates. The leaves were correctly oriented. However, this unit required adjustements according to the species to be treated. The cutting unit tests confirmed the results obtained with the cutting-force test-bed and the cutting of the branch was not frayed. It was then necessary to calibrate the contact sensors of the leaf nodes, both for their sensitivity and for their position with respect to the branch in the machine. After regulation, good behavior was found with the branches under test. The leaf removal operation was performed automatically, keeping the plants with our hands. No cuts were observed on the stem and the whole leaves were removed.

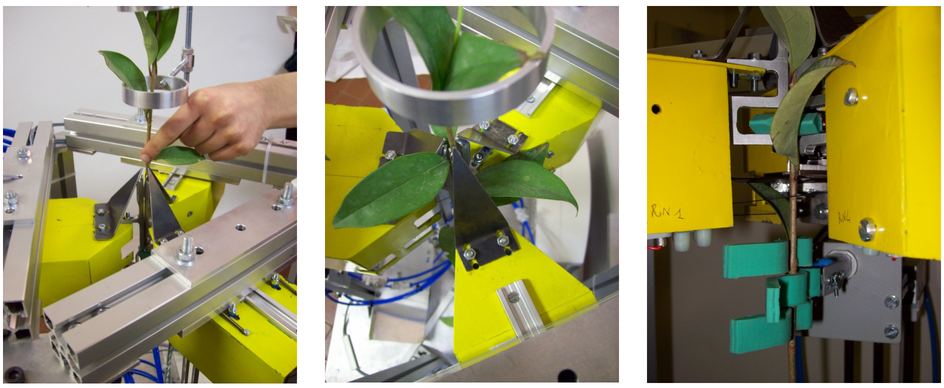

Figure 8 Images of the experimental laboratory campaign of the prototype

In Figure 8 some pictures of the prototype are visible during the validation tests.

The second laboratory test campaign aimed to validate the functionality of the whole prototype and the behavior was satisfactory. There were few stops in operation, but after some adjustments the machine worked properly. In some cases the machine has produced cuttings without leaves, because during the handling some upper leaves have been cut off. When the length of the remained part of the branch was not enough for a new cutting, the consequent stopping of the machine occurred. The tests were carried out by testing all the various modes of operation of the machine that have been shown to work properly.

The last test campaign was carried out in a greenhouse and the prototype was connected to a cartesian robot for the transfer of the cutting and subsequent insertion into the alveolus. Figure 9 shows the protptype of the automatic machine inside the working volume of the cartesian robot; no criticity in the interaction between the prototype and the cutting picking robot occurred due to an exchange of signals between the prototype and the robot: in particular, at the end of the cycle the prototype made available a signal for the robot and, subsequently, the robot commanded the release of the cutting from the gripping hand.

Figure 9 Image during the greenhouse validation campaign

5. CONCLUSIONS

This paper presents an innovative system for automating the cuttings production process to obtain young ornamental plants.

The process begins with a single branch of the parent plant, without secondary branches, which is manually inserted into the developed prototype.

The system is able to detect the leaf nodes, remove the leaves from its basal part, cut the stem to produce the cutting and make it available to the manipulation by an external robot for the subsequent phases of administration of hormones and insertion into the substrate. The proposed technical solution has a strong innovative content and has made it possible to reach the goal in a simple but reliable way. The paper shows the preliminary analyses to measure some characteristics of the selected ornamental plants, such as the cutting force, and the design and construction of the prototype. The different units that produce leaf displacement, branch cutting, sensors to locate leaf nodes and the control and command system of the prototype are also described.

Finally, the results of the tests carried out in the laboratory and in the greenhouse are illustrated. The research work is in progress for the optimization of the prototype. It aims to achieve the goal of extending the use of the automatic machine to plants with small leaves and to those without leaves. At the same time, the design of an automatic feeder of parent branches will be defined in order to obtain an automatic system

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