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AN EXPERIENCE ON THE AUTOMATION OF PLANT CUTTING TECHNIQUE FOR PROPAGATING PLANTS

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ABSTRACT

Plant cutting is a technique for propagating plants in which a piece of the source plant, called the cutting, is placed in the soil to grow as an indipendent plant. The cutting produces new roots and stems, and thus becomes a new plant. This technique is used in workshops to reproduce plants for selling. In this paper we are presenting a system to automate the plant cutting process of ornamental plants. The process starts with a single stem of the parent plant, with no branches. The system is able to cut the stem for producing the cutting, to remove the leaves from its basal part, and to manipulate it for the hormone subministration and for the insertion in the substrate. The design and the prototype of the automation machine, based on the pneumatic technology, is presented in this paper.

KEY WORDS

Plant cutting technique, pneumatics, automation,design

INTRODUCTION

Plant cutting is a technique for propagating plants in which a piece of the source plant, called the cutting, is placed in the soil to grow as an indipendent plant. The cutting produces new roots and stems, and thus becomes a new plant.

Many ornamental plants can be reproduced by cutting: Ligustrum, Photinia, Viburnum, Callistemon, Spiraea, etc. Many differences exist among these plants to apply this technique (type of cuttings, plant preparation, etc.). The reproduction process by cutting in a workshop follows 5 steps:

1. *The cutting of the parent plant*. Young and vigorous parent plants are used for obtaining branches, eventually with secondary branches, to be used for producing cuttings, Fig. 1. The parent branches have to be fully turgid. They should be irrigated to avoid the loosing of water, and short time has to be spent between the cut of the shoot and the placing of the cutting in the substrate.
2. *The stem cuttings*. The parent branches are cutted to produce cuttings. Each cutting has to include at least one leaf node, at the lower extremity, for the production of the new roots. The cuttings are collected together and mantained wet. If necessary they have to be rehydrated by soaking them in the water.

Figure 1 Parent plant used to obtain cuttings for reproduction

3. *The removal of the leaves*. Each cutting has to be worked to remove the leaves from the stem in the basal part of the cutting. This operation is important to prevent the leaves from being inserted in the substrate that can give problem to the new plant.
4. *The plant hormone subministration*. It consists of the immersion of the basal part of the cutting in a plant growth substance to promote the formation of roots.
5. *The insertion of the cuttings in the substrate*. Each cutting has to be put in a cell of a multi cells tray. The usual trays have 120 or 140 or 160 separate cells. A substrate is used for the cells to promote rooting and to prevent roots from breaking off.

These steps are usually followed in workshops to reproduce plants for selling. The work in these workshops is all handmade and it needs to reduce costs to be competitive on the market.
In this paper a pneumatic system to automate the plant cutting process of ornamental plants is presented. The process starts with a branch of the parent plant, with no secondary branches. The system is able to cut the stem for producing the cutting, to remove the leaves from its basal part, and to manipulate it for the hormone subministration and for the insertion in the substrate. The design and the prototype of this solution, based on the pneumatic technology, is also presented in the paper.

Figure 2 Photos showing the latter 4 steps in a plant cutting

THE AUTOMATIC SYSTEM FOR PLANT CUTTING

The stem of the branch can be considered like a long cylinder. From this stem starts secondary branches, leaves and, for some species, thorns. Considering only the ornamental plants that are very common in Europe, it is possible to classify them for the purpose of the automation system: plants without leaves, as Forsithia Viridissima, plants with medium size leaves but in small number, as Photinia Red Robin, plants with many leaves of medium size, as Viburnum Tinus Lucidum, plants with many leaves of small size, as Bruxus Sempervirens, and plants with many leaves of small size and with thorns, as Piracantha Moave. In this research the focus was on plants with medium size leaves, so that the extension of the results to plants with small size leaves or without leaves should not be so difficult. The table 1 shows the main characteristics of the branches of Photinia and Viburnum, that were selected for the automation system here proposed.

Table 1 Characteristics of Photinia and Viburnum branches

MAIN CHARACTERISTICS OF THE BRANCH	*Photinia Red Robin*	*Viburnum Tinus Lucidum*
Maximum diameter of the branch in the basal part	5 mm	6 mm
Minimum diameter of the branch in the upper part	4 mm	3 mm
Medium length of the branch	~ 500 mm	~ 400 mm
Maximum distance between stem and tip of the leaf	100 ÷ 105 mm	135 ÷ 140 mm
Minimum distance between stem and tip of the leaf	55 ÷ 65 mm	50 ÷ 60 mm
Maximum width of the leaf	50 mm	55 mm
Minimum width of the leaf	35 mm	40 mm
Length of the leaf-stalk	~ 10 mm	~ 20 mm
Medium distance between two consecutive leaf nodes on the stem	35 ÷ 40 mm	70 ÷ 80 mm
Angle between the stem and the leaf-stalk	≤ 60°	≤ 60°
Curvature of the branch	small or no curvature	small
Consistency of the stem	very high	medium
Compliance of the branch	low	medium
Consistency of leaf and leaf-stalk	very low	very low
Compliance of leaf and leaf-stalk	very high	very high
Resistence of leaf to removal	small	small

The design of the automatic system for plant cutting is started with the description of the 5 steps of the manual procedure that is used in workshops to produce young plants. The deepening of the technical aspects involved in each of these steps, and the discussion about the technical solution for the automation system, suggested us some considerations. The step 1, the cutting of the parent plant, will be skipped because of the range of each attribute of the parent plant: dimension, shape, secondary branches, consistency of the stems in the branch (softwood, semi-hardwood and hardwood), etc. Then a robot was chosen to do the steps 4 and 5 for two reasons. The first one is the final goal of this research project: to validate this system in an experimental greenhouse already equipped with the cartesian robot DEIAFA having a good working volume for our needs (2670x1540x780 mm^3). The second reason is that these steps involve only an handling problem, nothing more!

The main design choices of the automatic system are resumed in the following:

- the step 1 is skipped. The single branch, without secondary branches, of Photinia or Viburnum, is manually loaded into the automatic machine;
- the step 2, the stem cutting, and the step 3, the removal of the leaves, are executed by the automatic machine;
- at the end of the step 3, a gripper of a robot grasp the cutting from the machine and move it for doing the step 4, plant hormone subministration, and the step 5, insertion of cutting in the substrate.

So the operations of the automatic system defined in the steps from 2 to 5 are automatised by two subsystems: an automatic machine for the steps 2 and 3, and the cartesian robot DEIAFA for the steps 4 and 5.

In the following the technical specification of the automatic machine is described. The automatic machine has to:

- start the operations with a branch manually inserted inside the machine;
- sense the presence of the branch;
- feed the machine with the branch, minimising the effect of the curvature;
- move the leaves gently in such a way that the leaf nodes are located by the sensors;
- remove the leaves just in the basal part of the cutting;
- execute the cut of the cutting by a sharp knife to obtain a clean cut and preserving the leaves in the upper side;
- handle the cutting for the immersion in the plant growth substance and, after 5÷7 seconds, for the insertion in a cell of a multi cells tray.

The characteristics of leaf and leaf stalk of Photinia and Viburnum match very well with the needs of the system. For example the compliance is very useful during the movement of the leaves.

The automatic machine proposed consists of:

1. a device to feed the machine with the branch
2. a tool to move the leaves
3. sensors to locate the leaf nodes
4. a device to cut the branch
5. a device to remove the leaves

Following this design idea 3 subsystems can be identified: the device 1, the tool 2 together the sensors 3 and the device 4, the device 5. The Figure 3 shows a sketch of the idea of this automatic machine, where the 3 subsystems can be easily identified.

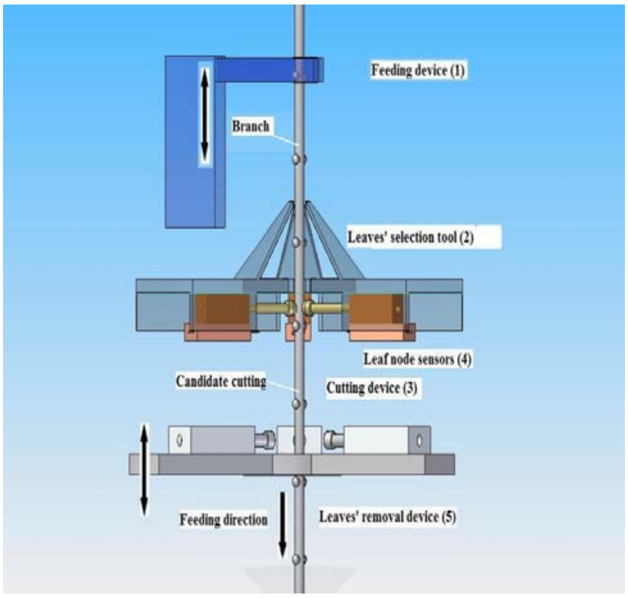


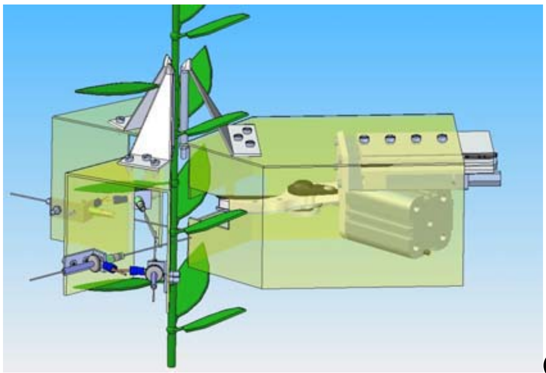
Figure 3 Idea of the automatic machine

Following this design idea a simple sequential functional chart was defined to settle the sequence of the steps involved in the automatic machine and in the robot operations, figure 4.

STEP 1. Feed the branch
LOOP UNTIL the length of the "candidate cutting" is in the range 9 ÷ 18 cm AND the cutting device is just under a leaf node
STEP 2. Stop the feed
STEP 3. Start the device for the removal of the leaves in the basal part
STEP 4. Move the gripper of the robot just to grasp the "candidate cutting" in the lower side
STEP 5. Cut the stem to obtain the cutting
STEP 6. Immerse the cutting in a plant growth substance
STEP 7. Insert the cutting in a cell with substrate to promote rooting
STEP 8. GOTO step 1

Figure 4 Sequential chart of the automatic system to produce cuttings starting from a branch

In the following the design of the second subsystem, formed by the tool 2, the sensors 3 and the device 4, is explained in detail. The design of the device 1 and 5 is in progress but the technical solution is already defined, figure 3. The device 1, feeding, is formed by a slide and a gripper. The device 5, leaves' removal, is formed by a couple of actuators with a special tool on the rods, that will go in contact with the leaves to be removed, mounted on a plate, and an handling actuator to move this plate along the stem. All the actuators are pneumatically actuated.
The tool 2 to move the leaves is formed by 3 fingers that are very closed each other to have a way through for the branch. Each finger has a compliance structure to adapt itself to different sizes and shapes of the branch. Each fingertip is shaped to move the leaf rigth or leftside during the feeding of the branch. In this way during the feeding the leaves are moved in one of the three simmetric circular sector free of the fixed frame, figure 5b. When the feeding of the branch is running the leaf nodes goes in contact with the contact sensors, so that they are located, figure 5. The contact sensors are rod-shaped mechanical sensors, with an electrical output, and the rod is positioned close to the stem. The tuning of these wires is very important to obtain a positive signal just when a leaf is passing through. Close to them but in the lower side the cut device is located. It has 1 dof (degree of freedom) to move itself frontside (working position) or rearside (rest position). A pneumatic slide is used for this purpose and the driving of the cutter is obtained by a pneumatic cylinder, figure 5. The knifes of the cutter are parts of commercial pruning shears, to be sure of the quality. In the Figure 5a is shown an assonometric view of this subsystem, while in figure 5b a bottom view is reported. All the drivers used in this design are pneumatics based. The choice of the pneumatics technology is motivated because of the agricultural environment. It is very dirty and very extreme as temperature, humidity and sunligth. Another reason is the semplicity of the technical solution that pneumatics technology can offer.


(a)

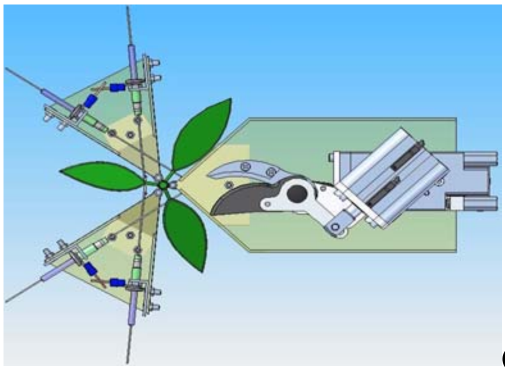

(b)

Figure 5 Views of the automatic machine's functional design

The power pneumatic circuit for the automatic machine is shown in the figure 6. It consists of 6 double effects cylinders plus 1 gripper for the feeding device. Each one of these actuators has a 4/2 electropneumatic valve to manage it, except the pneumatic slide for the feeding device. In this case a 4/3 valve is used, that's mean a 3 positions instead of 2 ones valve. This choice permits to obtain the stop of the slide in any position of the stroke, evntually by means of a pneumatic brake too (not shown in the figure 6). The total number of sensors and buttons used in the automatic machine is 22: 3 for start, stop/emergency and reset buttons, 3 sensors to locate the leaf nodes, 1 sensor to state that the branch is loaded and 15 endstroke sensors for cylinders, slides and gripper. All the 22 sensors are feeded with 24 Vdc to be connected to a commercial PLC (Programmable Logic Controller), that is used as controller of the automatic machine: 22 digital inputs and 12 digital outputs, to command the 6 electrovalves, are used.

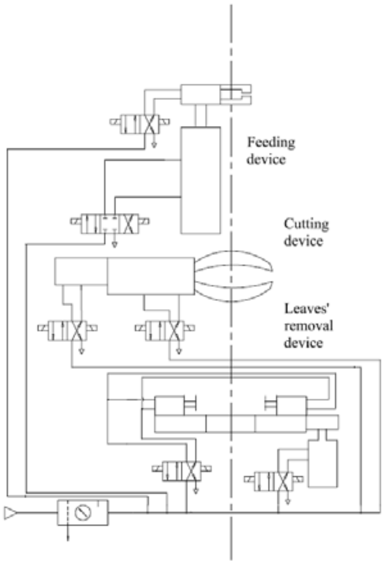


Figure 6 Power pneumatic circuit of the automatic machine

THE EXPERIMENTAL TESTS AND THE PROTOTYPING

The design procedure, described previously, requires to know the cutting force necessary to cut the branch. This data is necessary because of the importance to obtain a clean cut. For this reason an experimental setup was constructed based on a commercial pruning shears. A pneumatic cylinder was used to apply the cutting force on the shears, modifing the supply pressure with step of 0.05 MPa (0.5 bar). The tests were carried out with 4 different plants (Photinia red robin, Viburnum tinus lucidum, Forsithia viridissima and Bruxus sempervirens) for 3 different sizes of the stem, cutted from a parent branch just a couple of hours before the test. Two different positions of the stem were considered for the tests: stem in contact with the fixed blade and stem between fixed and mobile blade of the shears. The results for Photinia and Viburnum are shown in tables 2 and 3. The criterium adopted to classify the results of the test has 3 scores: B (bad) if the knife doesn't pass through the stem, NG (not good) if the knife pass through the stem, but the cut is not clean, G (good) if the cut is clean.

Table 2 Results of the cutting test on stems of Photinia Red Robin (G = good, NG = no good, B = bad)

Dynamic cutting force [N]		*176*	*235*	*294*	*353*	*411*
Stem close to fixed blade: diameter [mm]	*6,5*	B	B	NG	G	G
	5,5	B	B	G	G	G
	4,5	B	NG	G	G	G
Stem between mobile and fixed blade: diameter [mm]	*6,5*	B	B	G	G	G
	5,5	B	B	G	G	G
	4,5	B	NG	G	G	G

Table 3 Results of the cutting test on stems of Viburnum Tinus Lucidum (G = good, NG = no good, B = bad)

Dynamic cutting force [N]		*176*	*235*	*294*	*353*	*411*
Stem close to fixed blade: diameter [mm]	*6*	B	B	NG	G	G
	4,5	B	G	G	G	G
	3,5	B	G	G	G	G
Stem between mobile and fixed blade: diameter [mm]	*6*	B	B	G	G	G
	4,5	B	G	G	G	G
	3,5	NG	G	G	G	G

The results show that:

- the cutting force depends on the dimension of the stem, on the type of plant and on the cutting modality;
- the cut with the stem in contact with the blade gives badder results than the other one;
- appling a dynamic cutting force greater or equal to 353 N than the result is always a clean cut.

Considering that the maximum diameter of the stem is settled to 4 mm, because of the quality of the cutting that requires young branches, the design force of the cutting device was fixed at 235 N. The design calculation of the mechanism to drive the knife was made and a cylinder with a diameter of 32 mm and a stroke of 20 mm was chosen. The prototype of the cutting device was constructed and experimentally tested with good results.
The design of the tool to move the leaves has been already described previously. Here we can add some information more. It was designed on the characteristics of the plants Photinia and Viburnum. The 3 finger are positioned simmetrically with respect to the vertical axis with an angle of 120° on the base plane. The device is formed by 3 fingers, a cilindrical vane with vertical axis and a base frame. The base frame is a case and inside it the cutting device and the sensors for the leaf nodes are fixed. In the prototype each finger has the shape of a thin plate and is made by a rapid prototyping printer. The fingers are fixed at the base frame, in the bottom part. The cilindrical vane is very important to guide the branch inside the machine and to keep the same direction during the feeding. In the prototype this vane is made by 3 steel cilindrical pins positioned at 120° each other. Each pin is fixed in the upper part at the fingertip and in the lower part at the base frame. To verify the correct functionality of this tool many tests were conducted in the lab with good results.

Figure 7 Photos of the prototype

The sensors to locate the leaf nodes are made by a small tube and a small rod inside it. When a contact occurs the rod is pushed against the tube closing an electrical circuit. The sensors were made by ourselves in the laboratory and experimentally tested. The figure 7 shows two photos of the prototype of the subsystem, not completely assembled, that includes the tool to move the leaves, the sensors to locate the leaf nodes and the device to cut the branch.

CONCLUSIONS

In this paper a system to automate the plant cutting process of an ornamental plant is presented. The process starts with a single branch of the parent plant, with no secondary branches. The system is able to sense the leaf nodes, to cut the stem for producing the cutting, to remove the leaves from its basal part, and to manipulate it for the hormone subministration and for the insertion in the substrate. The technical solution proposed is innovative and the pneumatics technology helps to reach the goal in a simple but reliable way. The functional design and the prototype of the tool to move the leaves, of the sensors to locate the leaf nodes and of the device to cut the branch, are presented in detail. The results of the experimental tests for the cutting device for four different plants are also shown and discussed.
The work is in progress. The design of the last 2 devices, to feed the machine with the branch and to remove the leaves, are completed and the prototyping is the next step. Finally the experimental tests on these devices and on the complete automation machine will be carried out.

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