Development of a New Harvesting Module for Saffron Flower Detachment

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Abstract: The paper deals with the development of a new module for the detachment of the saffron flower. The module is conceived to be a part of the Agri-robot Zaffy. The module is composed of a gripper, a vision system, a pneumatic system for leaves shifting and a suction system for the harvesting of flowers after detachment. This paper describes the design of the module, with a special focus on the gripping device and on the vision system. The paper also shows the prototype of this module and the experimental activity performed in our research laboratory in order to measure the detachment capability and to test the vision system performances. Finally a preliminary experimental test was conducted in a Crocus cultivation. The preliminary results obtained show that the vision system has some critical positions in detecting the saffron flower.

Keywords: automated harvesting, saffron flower, mechatronics design

1. INTRODUCTION

Crocus Sativus flower appears as a tubule made of six violet similar petals, called lacinie. Among them, Crocus Sativus flower bears three bright red coloured stigmas from which spice, called saffron, is derived. Flower grows up among leaves: they appear as linear elongated bodies, dark green coloured. Typically, leaves appear quite close to flowers, as shown in Fig. 1. Only after a certain time period, leaves splay from the flower in order to lean to the ground.

Fig. 1. Crocus Sativus flower as it appears to the harvesting module

Saffron harvesting starts at the mid of October and can last at the most for four weeks. Harvesting is performed manually in the first hours of morning when the flowers are closed or when they just start to open. It is important to harvest flower when it is closed for the following reasons: closed flowers offer a greater easiness to be harvested; flowers are less damaged; stigmas are not exposed to sun light so that quality is granted; contacts between hands and stigmas do not happen in order to avoid stigmas deterioration by manipulation. The manual procedure of harvesting expects to catch the flower stem between the thumb and the forefinger; then, the stem can be cut (by nail) or can be detached. It is important to avoid leaves deterioration and, above all, leaves cutting. Critical aspects of the saffron harvesting are: manpower finding for a maximum of one month per year; high manpower cost incidence on the final saffron cost; harvesting procedure is very laborious for the worker's back. Finally, productivity is too low: a kilogram of saffron spice requires two hundreds thousand flowers; each hectare of cultivated ground requires about manpower for 1600 hours. Due to these reasons, the automation or semi-automation of saffron harvesting could lead to a productivity increase and to an improvement of operator work quality.

Many researchers are engaged on the automatic harvesting of fruits or vegetables, but at our knowledge just a research group of University of Cagliari in Italy is working on the saffron harvesting: *Ruggiu* (2006) and *Manuello* (2010). Our research group is engaged on the development of automated systems for agriculture, as described by *Raparelli* (2005, 2008), for oranges harvesting and for plant cutting technique. Research activities about saffron harvesting were focused at first on the characterization of plant, leaves and flowers of Crocus Sativus in order to define technical specifications for grippers and to define the more suitable harvesting strategy; then, the research activity in this area is carried on to design and to make prototypes of grippers. Based on our experience concerning experimental activities performed on previously realized gripper prototypes, reproducing a Crocus Sativus culture, it was obtained that the more suitable harvesting strategy requires stem and flower detachment coming upside with no stem cutting. For this reason, the last gripper prototype, described in *Raparelli.* (2006), was designed in order to perform the detachment of the flower. The prototype is made of two fingers provided with endings with suitable shapes, in order to shift leaves with no damages and a simple effect pneumatic actuator: it is an air pocket actuator, made in silicon rubber, in order to open and close the fingers of the gripper. Pressured air inside the air pocket provides its strain in order to close fingers. Opening is granted by two steel plates, acting as elastic spring. The harvesting strategy, tested in laboratory, experts the following phases: opening of fingers during the descent movement in order to move endings over the flower until the stem sides; closing of ending in order to approach the stem; ascent movement of the gripper for stem and flower detachment. The suitable shape of endings assured no cuttings or detachments of leaves. The same results were obtained by lateral approaches of the gripper to the stem. A similar approach was followed in order to design a new gripper for stem and flower detachment.

This work describes the development of a new harvesting module for saffron flower to be installed on Zaffy, the Agri-robot developed by Reda Elettronica – Italy, shown in Fig. 2. The new module is based on an innovative gripper, powered by a spring-actuator system and provided with a brake system. The new module is an alternative solution to the actual cutting module of Zaffy. The design and the prototyping of the new gripper are presented. Finally, the first experimental activity and the obtained results are described.

Fig. 2. The Agri-robot Zaffy

2. THE DEVELOPED HARVESTING MODULE

2.1. Robot Zaffy

Four wheels driving move Zaffy throughout rows in which saffron plants are planted so that they are located between the right and left wheels. A vision system, based on the colour of flower, detects flower position so that the harvesting module is placed on the flower. The harvesting module is moved on the horizontal plane by two servo-axes, in order to be located on the flower, and on the vertical plane by a third servo-axis in order to reach the flower from upside. A control and power unit feeds the drivers obtaining the movements of the robot. The original harvesting module reaches its goal by cutting and then sucking the saffron flower. It is made of a cylindrical pipe connected, in the upper ending, to the suction system and in the lower ending to a ring, on which the vision sensors are located, and to the cutting system. Around the ring, a second pipe, coaxial to the first one, is mounted and connected to the suction system in order to create an air jet on the leaves, just before the cutting action, and then the suction of the flower.

2.2. Technical specifications of the new module

The new module has to provide a new gripper for detachment of the stem and of the flower. It has to satisfy the same basic technical specifications of the actual module. In particular: it has to be provided with a jet air system in order to shift leaves just before the grasping of the stem; it has to be provided with a vision system in order to command the gripper for stem and flower detachment; it has to be provided with a suction system for flower movement after its detachment. When the module performs the descent movement, the air jet has to be activated to move away the leaves; the fingers of the gripper have to be open during the descent movement so that the flower can be scanned by the vision system; the vision system has to detect the profile of the flower; the gripper has to be closed when the stem reach the scan plane; the module has to start the ascent movement in order to perform the detachment of the stem and of the flower; then, the suction air has to be activated in order to move the flower toward the harvesting storage place. After the suction, the gripper has to be open again to process the next flower. On the basis of previous experimental activities, ***Raparelli*** (2006), the required force for gripper closing, in order to assure the detachment, has to be a minimum value of 2,5 N.

2.3. Design of the new module

The new module is composed of a gripper, a vision system for the timing of the gripping step, a pneumatic system to move away the leaves and a suction system for the harvesting of the flower.

The gripper is mounted on a vertical cylindrical pipe, quite similar to the previously described actual module. Two fingers, with a half moon shape, joined at the endings by two hinges, make the gripper. Fingers are mounted inside the cylindrical pipe. The fingers' closing occurs in correspondence of the intersection of the scan plane (of the vision system) and the symmetry axis of the cylindrical pipe. When the fingers are open, they are rotated in order to be placed inside the cylindrical wall of the pipe: this solution allows the optical scan of the flower profile without interferences with the fingers. The movement of the fingers is granted by an electromagnetic actuation. This choice was preferred to a pneumatic solution in order to avoid the use of a pneumatic compressor to be installed on Zaffy framework. The actuation system consists of a first solenoid, positioned on the external wall of the cylindrical pipe. The solenoid provides fingers opening by a double lever mechanism, transforming the linear movement in a rotary one. The fingers closing is provided by a spring; fingers, in closing position, remain at a fixed distance among them. A second solenoid has the aim to brake the gripper in opening configuration. When the stem is detected by the vision system, an electrical pulse reaches the brake solenoid so that the spring acts to close the fingers.

A photodetector and a scan plane compose the vision system. The photodetector is placed in a cylindrical darkroom, placed on one side of the cylindrical vertical pipe of the module; the scan plane is realized in correspondence of a plastic ring placed in the lower ending of the cylindrical vertical pipe. The photodetector is a monochrome optical sensor, used in order to detect the flower profile. A trans-impedance amplifier and a photodiode compose it, both mounted on the same chip. On the scan plane, horizontally, three emitting Leds and nine plastic fibre wires (Leaper Cabel, H9CV25B made by HESA SpA) are placed in the plastic ring. With reference to Fig. 3, Leds are placed in the upper part of the plastic ring according to an angular distance of 36°, 90° and 126° from the horizontal line counterclockwise; wires are placed in the lower part of the plastic ring with a starting distance of 18° from the horizontal line clockwise, and then positioned at an angular step of 18° each other. For each Led there are three opposing wires. The holes for fixing Leds and wires are radial, considering the bottom view of Fig. 3; on the same plastic ring, axial holes are manufactured in order to allow air flow for leaves shifting.

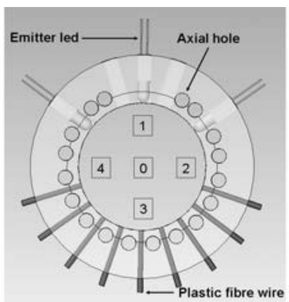

Fig. 3. Bottom view of the plastic ring with emitting Leds and plastic fibre wires

Each wire of plastic fibre is made of a 1 mm core in polymethylmethacrylate (PMMA) covered by an external cladding of fluorinated polymer with an external diameter of 2,2 mm. Light propagates inside the core by means of reflection due to the cladding. The opposite ending of each wire is mounted in a 3x3 matrix placed in the lower part of the cylindrical darkroom, as shown in Fig. 4. Light is transduced by a photodiode: it detects light intensity changes when the flower passes through the scan plane. On the basis of the light intensity changes it is possible to detect the flower profile. The vision system provides the closing command of the gripper and it is activated when the module starts to perform the descent movement.

A vacuum cleaner powered by a battery on board of Zaffy chassis feeds the pneumatic system for leaves shifting and for suction system. It is connected by a flexible pipe to the upper part of the cylindrical pipe and it has to reach two goals: it has to create a partial vacuum inside the cylindrical pipe in order to provide the flower suction; it has to provide an air jet to be directed to the described axial holes, inside the plastic ring, in order to shift the flower leaves from the action area of the gripper.

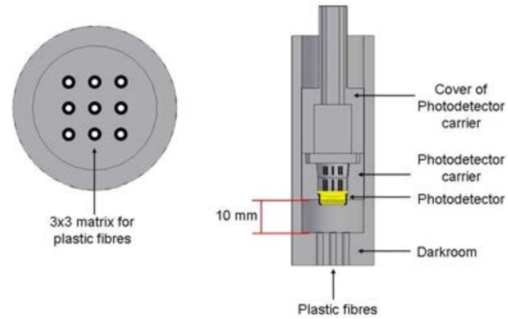

Fig. 4. Scheme of the darkroom bearing photodetector and plastic fibre wires

The new harvesting module is shown in Fig. 5 and technical data are reported in Table 1.

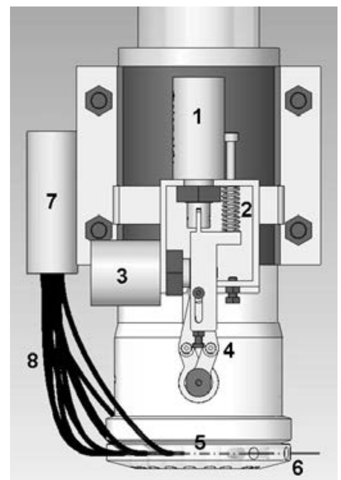

Fig. 5. The new module: 1) opening solenoid; 2) closing spring; 3) brake solenoid; 4) double lever mechanism; 5) scan plane; 6) plastic ring; 7) darkroom; 8) plastic fibre wires

3. THE EXPERIMENTAL ACTIVITY

The experimental activity was carried out mainly in the research laboratory, but preliminary experimental tests were carried out in a Crocus cultivation. These experimental tests were focused in order to study mainly two different aspects: the detachment capability of this new module and the performance of the vision system.

Detachment capability was evaluated as the maximum sustained payload by the gripper. Models of saffron flower were created for the experimental tests, because of the impossibility to have saffron flowers in a period of the year different from October. In these specimens it was difficult to reproduce the stiffness of the saffron flower stem. Three different types of wire were considered to simulate the stem: a plastic wire, a wood wire and a cardboard wire with external diameters about equal to 2 mm. A plastic glass was linked to each wire, during the tests, to apply the load, filling it with water. Adding quantities of water, while the fingers of the gripper grasp the wire, as shown in Fig. 6, it is possible to increase payload. A 5 cm^3 syringe is used to increase very slowly the quantity of water inside the glass: step of 0.5 cm^3. The water volume of 0.5 cm^3 means a mass of 0.5 grams and a weight of 5 mN.

Table 1. Technical data

***Opening Solenoid**: BLP 122-420-610-620*				
action	magnetic force [N]	stroke [mm]	power consumption [W]	power supply [V dc]
traction	**20**	**18**	**10**	**12**
***Closing Spring**: compression spring D11290*				
wire diameter [mm]	external diameter [mm]	length at rest [mm]	elastic constant k [N/mm]	
0,50	**5**	**44,5**	**0,27**	
***Brake Solenoid**: Mechetronics SD283A6P2*				
stroke [mm]	power consumption [W]	power supply [V dc]		
6,5	**11**	**24**		
***Optical sensor**: Burr-Brown OPT301M (Texas Instruments)*				
bandwidth [kHz]	diameter [mm]	Power supply [V dc]		
4	**9,08**	**2,25**		
rise time [ns]	temperature range [°C]	adjustment time [ns]		
90000	**-55 to 125**	**240000**		
Emitter led				
diameter [mm]	average light intensity [mcd]	Power supply [V]	view angle range	
5	**20000**	**3,1** (at 25mA) **3,3** (at 35mA)	**15°-20°**	

The maximum sustained payload was measured as the weight of water necessary to allow the detachment of the wire, by a weighing device. Each test was performed in three different positions of the wire: in the centre, in the left and in the right endings of the fingers. Each wire was submitted to three tests. A second type of fingers ,as shown in Fig. 6, was added to the external part of the module in order to lower the detachment area for all those flowers that came out from the ground partially. The external and the internal fingers, shaped in the same way, cannot be used at a time in the module, also because it is necessary to choice which couple of fingers to assemble on the module. The experimental tests were performed with internal and external fingers and the results are summarized in Table 2, first couple solenoid-spring.

Fig. 6. Test bed for measurement of detachment capability

Table 2. Closing force of the gripper for 2 couples solenoid-spring

Opening solenoid **BLP 122-420-610-620** - Spring **D11290**				
Type of fingers	Average payload vs. stem material [N]			Average pay load [N]
	plastic	wood	cardboard	
Internal	**1,30**	**1,32**	**1,40**	**1,34**
External	**0,72**	**0,65**	**1,08**	**0,82**

Opening solenoid **BLP 124-420-610-620** - Spring **D12300**				
Type of fingers	Average pay load vs. stem material [N]			Average pay load [N]
	plastic	wood	cardboard	
Internal	**2,81**	**2,91**	**3,41**	**3,04**
External	**2,47**	**2,04**	**1,09**	**1,87**

Given that the closing force doesn't satisfy the technical specification of 2,5 N, the opening solenoid and closing spring were substituted respectively by the solenoid BLP 124-420-610-620 (magnetic force of 50 N; power consumption equal to 17 W) and by the compression spring D12300 (wire diameter of 1,25 mm; external diameter of 16 mm; length at rest of 40,5 mm; spring constant equal to 1,73 N/mm). A second set of tests was performed with the same methodology previously described. The second couple solenoid-spring of Table 2 summarizes the obtained results.

The final configuration of the new harvesting module expects the new solenoid, the new compression spring and the use of internal fingers. Some changes of module design were adopted due to dimensions of the module. The final module appears as shown in Fig. 7.

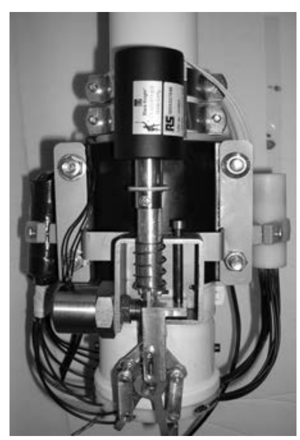

Fig. 7. The final version of the new harvesting module

The performance of the vision system was evaluated as the capability of the photodiode to detect and so reconstruct the profile of the flower, on the basis of the light intensity changes. The presence in the scan plane of an obstacle, in this case of the flower, among Leds and wires, is the reason of a lowering of the measured signal (electric tension), proportional to the obstacle dimension. Furthermore, it depends on the position of the flower as regards the centre of the cylindrical pipe. Two specimens of flowers were manufactured: one simulates an open flower, the other a closed one. It was necessary to simulate these two conditions because, during harvesting, it could be possible to detect open and closed flowers, depending on the day hour. Dimensions of the specimens, as shown in Fig. 8, are similar to the flower one. Tests were performed having the cylindrical pipe in a fixed position and moving the specimens vertically inside it. Specimens were moved by hand, but the vertical stroke was assured by a sledge mounted on an external metal ruler, placed in vertical position, as shown in Fig. 9. The initial position of the flower expects the upper extremity of it to stay just under the scan plane. The maximum stroke was fixed to 36 mm, because the light has to hit the flower and partially the stem. Specimens were introduced in five different area of the scan plane, simulating where the flowers can stay during harvesting: a central area (0) and four lateral ones (1,2,3 and 4) describing a cross, as labelled in Fig. 3.

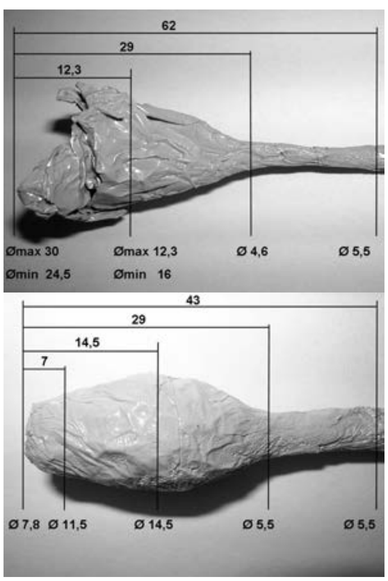

Fig. 8. The two models of the saffron flower used in the test. The dimensions are in mm

The output signal of the vision system shows different behaviours, depending on the position of the flower in the scan plane. With reference to Fig. 3, when the flower stays in the centre position "0", the output signal shows always the best behaviour for both specimens: high value at the beginning, 0.3 - 0.5 V, than it goes down, less than 0.1 V, and finally it rises to a high value when it hits the stem, 0.3 – 0.4 V. It means that the vision system is able to detect the flower profile and can be used as switch signal to close the gripper. A typical output of the test is shown in Fig. 10 for both the specimens.

In the other areas of the scan plane, three different cases result, as follows: the output signal is similar to the previous one for the central area; the output signal goes down to a very low value, about 0.0 V, with no rising in the final part of the stroke; the output signal goes down in a more narrow stroke range than before and then rises to about the initial value. In both the last two cases, vision system is not able to detect the flower profile, as it is necessary for the harvesting module.

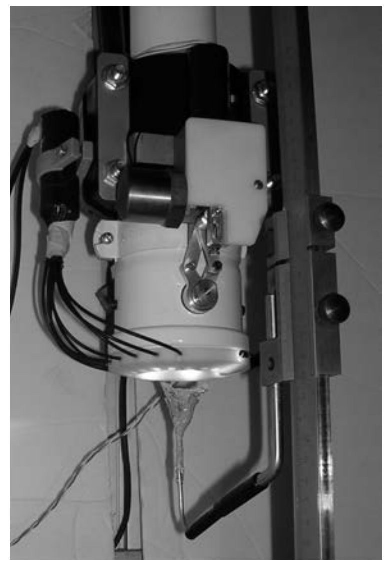

Fig. 9. Test bed of the vision system

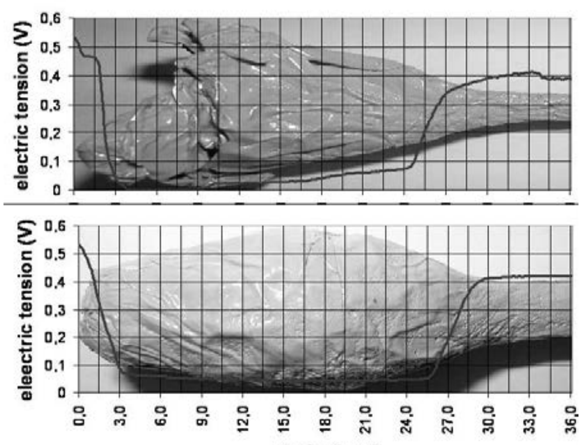

Fig. 10. Output signal of the vision system with introduction of the specimen in the central area "0"

Preliminary experimental tests were performed, in open air and with natural sunlight, in a real Crocus Sativus cultivation, using the new module directly mounted on Zaffy. The correct flower detachment was registered in 60% of harvesting actions; in the other cases, an evident damage of the flower was registered. The reasons of this behaviour could be these ones: the lateral position of the flower in the scan plane or the not perfect flowering of the saffron flower. This behaviour need to be deepen in a future work.

4. CONCLUSIONS

A new harvesting module for saffron flower detachment, as a part of the Agri-robot Zaffy, was presented. The electromagnetic actuation, based on two solenoids and a compression spring, was successful proposed and experimentally validated. Some modification to the original design was carried out due to dissatisfaction of the closing force of gripper, shown during the experimental tests in the research lab. Following the preliminary experimental results in a Crocus cultivation, described in the paper, the harvesting module is able to detach stem and saffron flower with successful results in 60% of harvesting actions. Some critical aspects about vision system are to be solved: the flower profile is correctly detected only when the flower stays in the centre of the scan plane. Next developments will be based on the optimization of the visual system in order to detect the flower profile in every position of the scan plane.

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REFERENCES

Manuello Bertetto, A., Falchi, C., Pinna, R. and Ricciu, R. (2010). An Integrated Device for Saffron Flowers Detaching and Harvesting. *Proceedings of the Robotics in Alpe-Adria-Danube Region (RAAD), 2010 IEEE 19th International Workshop on Robotics*, 93-98, 24-26 June 2010

Raparelli, T., Beomonte Zobel, P. and Durante, F. (2005). Development of a picking device of an orange harvesting machine. *6th International Conference on Fluid Power, Transmission and Control, ICFP' 2005*, 335-339, 5-8 April, 2005

Raparelli, T., Beomonte Zobel, P., Durante, F. and Antonelli, M. (2006). Dispositivi per la raccolta automatica del fiore dello zafferano. (in Italian) *Trasmissioni di potenza oleodinamica-pneumatica-lubrificazione*, volume 11, 102-106

Raparelli, T., Beomonte Zobel, P., Antonelli, M. and Durante, F. (2008). An experience on the automation of plant cutting technique for propagating plants. *7th JFPS International Symposium on Fluid Power*, volume 3, 809-814, 15-18 September 2008

Ruggiu M., Manuello Bertetto A., (2006), A mechanical device for harvesting crocus sativus (Saffron) flowers. *Applied Engineering in Agriculture, vol. 22 ISSN: 0883-8542*