PERSPECTIVE ON SAFFRON SPICE SEPARATION BASED ON CONTROLLED FLUID DYNAMIC SYSTEM AND COMPUTER VISION

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ABSTRACT

To correctly develop, validate and mass-produce a saffron spice separation machine it is mandatory to particularly know physical and aerodynamics characteristics of the flower. To achieve this goal a wind tunnel is developed by the authors. The data obtained with the wind tunnel are used to get a rough calibration of a fluid dynamic separation device based on the differences of the terminal velocities of the parts that must be separated. To fine-tuning of the machine, a computer-vision system and a controller are developed to automatically adapt the machine parameter following the variability of the saffron spice.

Keywords: Saffron, Computer Vision, Aerodynamics (max 5 words)

1 INTRODUCTION

The use of Saffron Flower (Crocus sativus) has its origin in very ancient time. The first known reference to saffron dates back to the period between 1600 and 1700 BC. The actual name comes from the Greek mythology, which narrates that the red colour of the stigmas is from the blood of Krokos after being wounded by the god Mercury [1].

Saffron is an annual plant and it is categorized under the Iridaceae family. Every flower is composed by six petals, three anthers and one stigma. Stigma is the more important part of the flower and it has many applications in different fields like food, cosmetics (e.g. as a dye for fabrics or sunscreen [2]), medical and pharmaceutical ones.

The culinary use of saffron is the most known but in ancient text by Hippocrates, Dioscorides or Galinos other uses are reported such as therapeutic substance. [1] Those therapeutic properties – back then only theorized – have been recently endorsed by numerous studies that have demonstrated the benefit of using saffron thanks to its active principle (like safranal, crocins and pirocrocins).

Among numerous studies about the beneficial properties of the saffron spice on the human body, the most important ones have enlighted anti-depressant [3], anti-inflammatory [4] and anti-aging [5] [6] agent.

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Most recent studies focus on the therapeutic use of the saffron spice in order to cure neurodegenerative and brain-related diseases; in particular, it has been shown that this spice has positive effects on the treatment of Alzheimer's and Parkinson's condition [7] [8], degenerative eyesight disease [9] and as neuroprotective agent from metal toxicity [10]. Moreover, different researches have shown that the intensity and vibrancy of spice's colour is a valid indicator of product and its active principle's quality [11] [12].

The increasing demand of saffron due to the ever-expanding use and the impossibility to meet the new demand – due to production limitation – has steadily increased the spice's price.

Considering the flower dimension, structurally delicacy and overall fragility, all the phases of the production are carried out manually only. The saffron cultivation is made up of different phases and each phase has a different impact in terms of work time as can be seen in Table I.

Table I - Percentage amount of human work needed during saffron cultivation

	Percentage	Hours/man necessary to produce 1 Kg of dried spice
Planting bulbs	10%	50 hours
Harvesting	30%	150 hours
Separation	40%	200 hours
Drying	10%	50 hours
Packaging	10%	50 hours

Harvesting phases are the most intensive in term of labour: an expert saffron harvester can pick (considering also the resting time) a maximum of one thousand flowers per hour; to obtain one kilogram of dried spice, one hundred and fifty thousand flowers is required, thus a picker would employ 150 hours to obtain a so little amount of dried spice.

Many studies propose automated solutions for harvesting the saffron flower on the field. An interesting proposal is referred to in [13]. This device is a lightweight, portable, compressed air powered device. In this system, a hand equipped with fingers detaches the flower, which is sucked up. Detachment occurs without damaging the leaves that can surround the flower in the field. Other automated harvesting systems are discussed in order to complete the harvesting phase avoiding to carry out this phase manually, with the consequence of tiring the workers and the need for specialized personnel. In [14] the *Zaffy* rover that achieved a success rate of about 60% is presented. The most time-consuming phase is the separation: in fact, on average, one hundred minutes are required to separate one thousand flowers, so to obtain a kilogram of dried spice with only one worker would require 250 hours. Its expensiveness is due to the low productiveness (low yield per farmed area) and the high number of manual labour necessary to grow, harvest, separate and dry the saffron spice from the flower.

Is also worth noting that the countries, which have a lower cost per hour for workers, have a significant advantage on producing saffron due to the lower cost of production and the higher margin of profit [15]. Iran is the main producer of saffron with around the 90% of global production, with 108086 ha of cultivated areas and 376 tons of dried spice produced per year [11]. The remaining 10% is produced by Greece, India, Spain and Italy. In Italy about 50 ha are intended for saffron cultivation, 35 of which are in Sardinia and the other 15 ha are cultivated in Tuscany, Marche, Abruzzo and Piemonte [16]. Through mechanization there is the possibility to improve by a huge margin the saffron production that today in Europe has only a marginal impact [15]; during past years numerous attempts have been made in order to improve the harvesting and the separation phases of the production. In [17] [18] authors have designed and mathematically modelled a portable device to pick the flower; the harvesting device has a simple design and it is capable to cut the flower by using only one actuated degree of freedom. Regarding the separation phase, the most effective principle is the use of terminal velocity of the flower's part in order to separate the saffron in its component; numerous studies like [18] [19] and [20] show that this type of design is feasible and affordable, but to obtain the necessary consistency of result – necessary to use the machine with a high rate of speed – it is important to develop a machine with the capacity to auto-tune itself on the optimal terminal velocity for that specific batch of flower. Computer Vision Systems (CVS) are widely used in the industrial sector as quality control system and numerous researches have implemented CVS system in the agricultural field to control and improve the growing status of fruit and vegetable on the field.

Also, CVS are also implemented by expert with the aim to try to recognise adulteration of fruit and vegetable like bananas, beef, fish, potato chips and coffee beans. In [12] the authors have exploited the typical red colour of the stigma to train and develop a CVS system to recognise adulterated and/or poor quality saffron, with very promising results. In the agricultural sector – and more specifically on saffron - CVS have been implemented with different uses and it has shown its potential: in [21] the authors, with the intent of using it for locating the flower on the field, have developed an algorithm that is able to differentiate the flower from the background and foreign object that may be on the field; this method uses the colour space to identify the flower. In [22] and [23] a CVS is implemented and used to recognise a saffron flower and identify the correct point to cut the flower from the corolla tube and mechanically divide the petals, the anthers and the stigma from each other. The approach seems to be promising and the CVS algorithm is suitable to be adapted in the research that is showed here. This work aims at becoming the *trait d'union* between the work done by the authors – and partially illustrated in [20] – and the preexisting work, done by other authors, in order to try and achieve a proof-of-concept that can be implemented and developed as definitive solution for separating the saffron spice from the flower. This will be achieved mainly by analyzing the terminal velocity of the components of the saffron flower, analyzing the different technique to separate them and by suggesting a valid implementation of a CVS system to control the effectiveness of the separation and increase the grade of purity of the separated product.

2 MATERIALS AND METHODS

2.1 TERMINAL VELOCITY OF SAFFRON COMPONENTS

In [20] the authors have shown that the components of the saffron flower are defined by a very specific range of speed. This range of speed has been measured for each component was measured with a vertical wind tunnel that has been built specifically for this use. The results were aligned also with the speed measured by other researchers like in [24] and [19]. Those data are reported in Table 2 for the ease of the reader. These ranges of speed are constant and very similar despite the variance in bulb dimension or the variance of the saffron bulbs. Therefore, these can be used as a starting point to set the separation device up; with those speed the separation will be effective but not with the greatest results in terms of efficiency or purity.

Table II –Terminal velocity ranges of Saffron flower parts

	Range of velocity
Petals	1,6 – 1,9 m/s
Anthers	1,6 – 2,4 m/s
Stigmas	2,7 – 3,5 m/s

The measurement used to extrapolate this data has been analyzed using the simple analysis of variance (ANOVA) and then the means were separated using the Tuckey test with a 95% confidence interval. Those analysis have proved that the data is meaningful – the null hypothesis is false – and all the mean are independent from each other.

2.2 SEPARATING DEVICES AND THEIR CONFIGURATION

Different researches have shown that different approaches are possible to create a separating machine; the main three are the parallel plate type, the ones with vertical configuration and the horizontal configuration. The parallel type machine is very little documented [25] and due to the configuration of the air flow – that approaches laterally the material, creating a parabola motion on the flower parts – is not suitable for the application here explained. The vertical machine could be designed using two different types of air flow; this type of machine could be either in a push [26] or a pull [20] configuration. This type of device can also be implemented with a mixed flow, using a vertical flow mixed with a centrifugal flow (cyclone) [16] [27]. Some researchers [28] have developed a horizontal separating machine composed by a long horizontal conveyor belt; at the start the conveyor belt there is a station for the operator to insert the flower – and to divide its component using a little cutting tool – then the parts will drop on the conveyor belt, move along the machine and pass under several vent, connected to the aspirator, that will remove the undesired part. Each vent is regulated with a slightly higher speed from the previous one in order to obtain a product as much pure as possible at the end of the conveyor belt, where a bucket is positioned to recover all the stigmas.

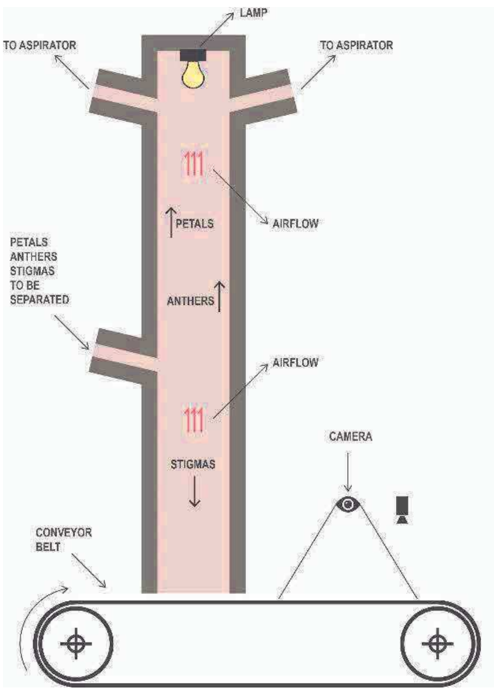

Figure 1 Diagram showing the layout of the vertical separator

The horizontal machine – despite the lack of public documentation – is very functional from the ergonomic side, but it has some disadvantages, arising from the fact that is developed with an industrial-like layout, that carries a considerable footprint, a high weight and a poor transportability. Note that this type configuration – despite its disadvantages – isn't less effective during the separation phase then the vertical one; but the authors' objective is to develop a system that is easy to use, relatively low-cost and easily transportable to minimize the time between the harvest and the separation phases, which is a crucial factor to maintain the quality of the product. Every separation system – despite of its configuration – is composed by one or more fans, aspirators or blowers; these components are fundamental to create the correct air flow inside the separation device and the air flow is the fundamental parameter – like shown in [20] – that will need to be regulated precisely to implement correctly the separation of the saffron flowers part's. For the purpose of this research the authors will focus on the vertical configuration for the ease of the developing and explain, despite developing a system that is "separator-agnostic" and that will work independently from the configuration of the separator.

2.3 CVS CONFIGURATION

After the material has been divided by the air flow, the valuable part of the material is dropped on a conveyor belt; above the conveyor belt a camera (NV-GS15) has been positioned with the aim to capture all the material passing on the belt. The camera is connected to the PC that will elaborate the image with a series of filter to count and recognize the object on the conveyor belt.

As can be seen in Figure 1 the image is processed by different filters in this order:

1. Median Filter: this is used to reduce the weight of the image and to smooth out the contour of the image
2. Gamma & Intensity filter: they adjust the image to make it lighter and to enhance the object from the background
3. Threshold: to remove the background from the object
4. Flood fill & Blob Filter: create object "blobs" that the program uses to count and operate on them; each blob represents an object on the conveyor belt
5. Blob Colorize: it is used to color the blob based on the color and dimension of the object to correct identify it as a petals, anthers, stigma or foreign object.
6. Custom Script: it counts the blobs, categorizes them and analyzes the variation in presence of anthers.

During the processing of the image, each phase has a very specific function to simplify the correct recognition of each part of the flower. The median filter is used to erode the border of each component and to smooth out any white noise or little imperfection by replacing pixels with the middle pixels value selected from a window of 4x4 pixels. The gamma filter is used to map the pixels intensities and help to obtain a more viewable image; adjusting the gamma leave the highest and the lowest pixels intensities at the same value, while increase the mid-tone pixels in intensities.

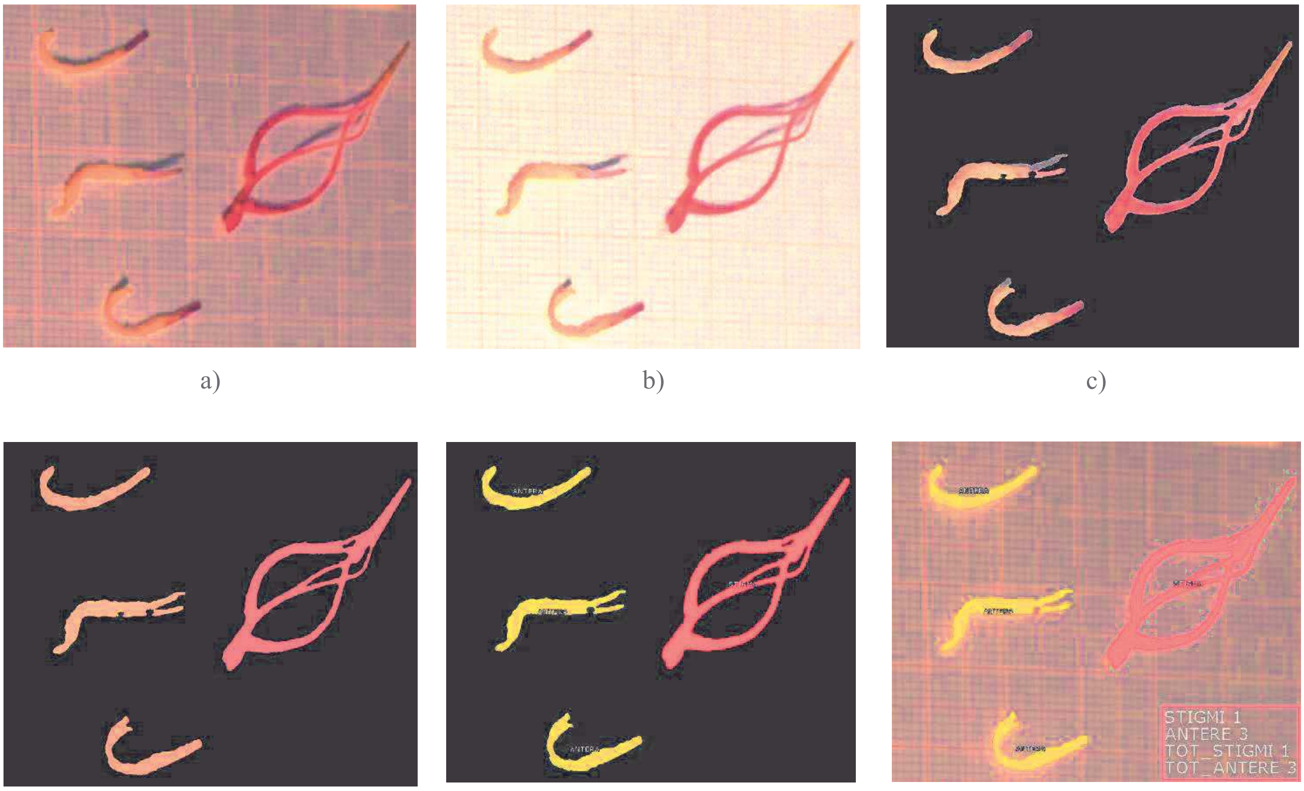

Figure 2 Image processing as seen by CVS system in each step; a) original image as acquired by the camera; b) image after Gamma and Intensity correction; c) Image with threshold applied to remove the background; d) Flood fill and Blob filter applied to the previous image; e) Blob Colorize applied with custom color - Red for the stigma and yellow for the anthers - with the name in overlay; f) Final image with the object correctly recognized and a little table shoring the count and a total count.

The intensity filter is used to brighten the image while maintaining the correct ratio among color; in this case a “Shift to White” filter is used. The threshold filter is used to binarize the image; this is achieved by using the Ridler-Calvard method in order to compute the threshold value and to set pixels to white if their value is greater of the threshold, otherwise to set them to black.

Flood fill and the blob filter are used to equalize the color of the object (for example, after the application of this filter, petals will be a purple blob, anthers will be yellow blob and anthers are red blob).

The blob colorize filter is used to recognize each blob by using a combination of dimensions and colors; after a blob is correctly recognized, a custom color - selected based on the type of the object - is applied and an overlayed text identifying the object is positioned at the center of the blob. After this process a custom script is run to count the stigmas and anthers that are recognized by the camera and this information is overlayed on the image.

2.3 AIR SPEED CONTROL PROPOSAL

The CVS program after the image elaboration could be used to adapt the air speed of the separator to correctly find the speed that can lead to 100% of purity of the separated material (namely no petals or anthers in separated product). It is known that, in order to have a perfect separation, the air speed should theoretically be regulated in the range between 2,4 m/s and 2,7 m/s but to boundary conditions like: humidity, adhesion between flower parts, static and dynamic losses, interaction between the separator and flower parts and incorrect feeding by the operator, the setpoint is constantly fluctuating and very small adjustment are necessary. To achieve this objective two solutions could be implemented, both using a closed loop system. The first solution uses only the output of the CVS system to regulate the speed; the logic is very simple: if the CVS sees an anther or a petal it counts them, then applies a mean value over a short period of time – to avoid a sudden increase of air speed – and then commands via serial the increase of the speed of the motor (Figure 3). The problem with this system is that for the controller it is impossible to know when it is “overcorrecting” and the air speed is too high, with the consequence of removing also stigmas. To correct this issue, we can implement an anemometer to have a reading of the current air speed. With this setup, the CVS monitors the speed of the airflow, but in conjunction with the reading of the anemometer; in this way the air flow is allowed to variate freely but with an upper limit; that limit is set up at the lowest terminal velocity of the stigmas (at around 2.7-2.8 m/s).

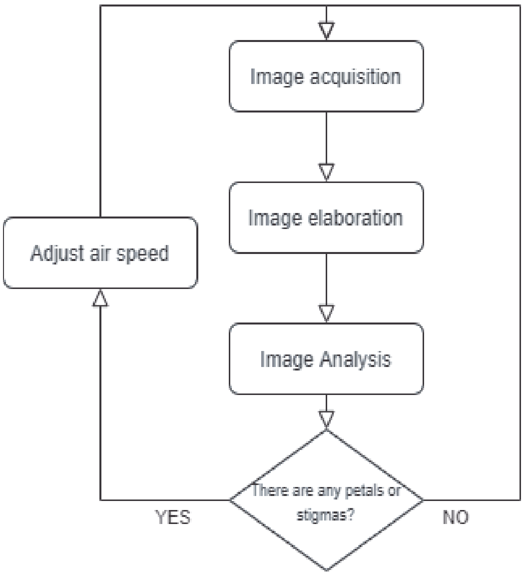

Figure 3 Flowchart of the proposed algorithm

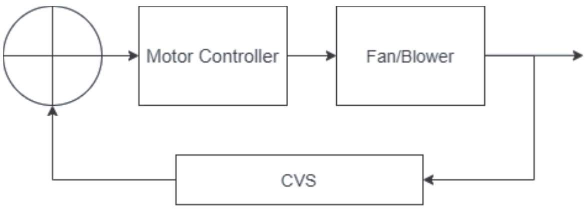

Figure 4 Controller scheme with only CVS

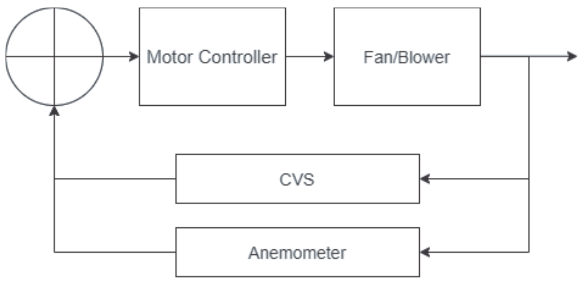

Figure 5 Controller with CVS and Anemometer

The PC with the CVS software can communicate with the motor controller – a board with a TRIAC to change the voltage of the supply of the motor or a digital inverter which can variate the frequency of the supply – via serial and can impose a decrease or a decrease in air speed. In the most basic configuration, an Arduino board can be used to command a step-by-step motor connected to a potentiometer board. The anemometer is connected via serial port to the PC; the anemometer should have at least these specifications: speed range between 0.1 m/s to 10 m/s, accuracy ± 0.1 m/s and resolution of 0.01 m/s.

3 CONCLUSIONS

In this research have been analyzed different researches regarding saffron separation and computer vision systems with the main objective to better understand the discovery already made. This proof-of-concept aims at integrating the already existing literature and the new experiment done by the authors of this paper in order to try and develop a more complete solution that could reach the production phase. The system here proposed could be adapted, with very little modification, to any type of saffron separator and to almost every type of separator that uses air flow and terminal velocity as physic principle to differentiate the component that need to be separated.
Future work will concern the on-field application of the plants, built with the defined controls. Particular attention will be spent to the definition of a strategy that imposes a control architecture with a gradual increase in the suction capacity, until the elements to be eliminated disappear. This will be realized with the aim to approach for defect to the physical more efficient separation parameters values, to avoid a situation where the parts that are not to be eliminated are mistakenly aspirated

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