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Potato Operation: automatic detection of potato diseases

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ABSTRACT

The Potato Operation is a collaborative, multidisciplinary project in the domain of destructive testing of agricultural products. It aims at automatizing pulp sampling of potatoes in order to detect possible viral diseases. Such viruses can decrease fields productivity by a factor of up to ten.

A machine, composed of three conveyor belts, a vision system, a robotic arm and controlled by a PC has been built. Potatoes are brought one by one from a bulk to the vision system, where they are seized by a rotating holding device. The sprouts, where the viral activity is maximum, are then detected by an active vision process operating on multiple views. The 3D coordinates of the sampling point are communicated to the robot arm holding a drill. Some flesh is then sampled by the drill, then deposited into an Elisa plate. After sampling, the robot arm washes the drill in order to prevent any contamination.

The PC computer simultaneously controls three processes, the conveying of the potatoes, the vision algorithms and the sampling procedure. The master process, that is the vision procedure, makes use of three methods to achieve the sprouts detection. A profile analysis first locates the sprouts as protuberances. Two frontal analyses, respectively based on fluorescence and local variance, confirm the previous detection and provide the 3D coordinate of the sampling zone. The other two processes work by interruption of the master process.

Keywords: agrotics, computer vision, viral diseases detection, destructive testing.

1. OVERVIEW

1.1 Constraints of the system

The purpose of the system is to automate pulp sampling of potatoes in order to detect possible viral diseases^{3,8,5}. The viral activity is maximal under the sprouts of the potato, and is proportional to the size of these sprouts. Sprouts tend to grow with some preference at one of the extremities called the rose-end of the potato. The system must be robust enough to overcome the high variability of natural shapes and the natural defects of the surface (abrasion damages, plaques, mud, etc.).

The drill used for the pulp extraction has to cut at the penetration point, with an angle ρ , constrained with respect to the local normal to the potato surface by $10^\circ \leq \rho \leq 40^\circ$. This angle is determined by the fact that the drill has to sample in a zone defined by a circular area of approximately 3mm around the sprout, to a depth of 10mm.

The processing time for one analysis cycle, from the grasping to the discarding of a potato, should be of the order of 10 to 20 seconds for the system to be a viable alternative to human manipulations. Also, the system must be able to perform automatically such cycles for about 4 hours, which is the planned autonomy. The tolerated error rate has to be less than 5%, while the rejection rate should not exceed 20%. Finally, the whole system should have a reduced number of input parameters in order to run in an automatic fashion.

1.2 Detection strategy

The aim here is to furnish to the robot the 3D coordinates of the best sprout, where it has to drill. Whatever the detection method used, it will be based on the combination of at least two images, since one image contains only 2D information.

On a first image, the best sprout is detected and the shape of the potato is fitted with an ellipsoid. The potato is then rotated, bringing the previously detected sprout in front of and at a known distance of the camera (the position of the rotation axes is known). The sprout is then detected again, and the combination of these two images furnishes the 3D coordinates of the penetration point.

1.3 Robotic setup

The robotic solution is composed of the following steps, implemented in a modular way in order to make them independent from the detection strategy^{2,1,6} (see also section 2):

- the potatoes are conveyed from a bulk to a V-shaped conveyor (CB2, Fig.2) by means of the first conveyor belt (CB1). CB1 is stopped when enough potatoes are detected on CB2;
- these potatoes are then guided towards a second V-shaped belt (CB3) in small bunches of 3 to 5 potatoes. The arrival of a potato on CB3 will stop the belt CB2;
- when arrived at the extremity of CB3, the last belt is stopped, the potato is picked by a rotating axis and then presented to the sprout detection device;
- sprouts are detected and the 3D coordinates of the penetration point are communicated to the robot arm;
- the drilling and pulp sampling is then performed by the arm, and the sample is deposited into an Eliza plate;
- the potato is finally ejected by the holding device, and the drill is washed;
- a new cycle can then begin.

The sequence described above shows the path of a potato, but some of these steps are performed in parallel. As an example, the ejection of the potato is done simultaneously with the depositing of the pulp sample and with the washing of the drill, while the next potato is brought for the next detection.

1.4 Software organization

The software is organized in three main layers (see Fig. 1). The first one consists of the hardware interfaces, allowing us to access the different physical elements of the system. It is composed of four modules:

- the vision card module;
- the Galil interface for the control of the holding device and the filter to be put in front of the camera (see section 3.2);
- an interface for the robot and the Tecan dilutor, reachable through the RS 232;
- several drivers for the control of the conveyor belts, the presence detectors and the rotation of the axis of the holding device.

The second layer is composed of four other modules that will control the device modules described above with very simple and transparent procedures, such as “RotateAxis(angle)”, “MoveRobotTo()” or “GrabImage()”. These four modules are:

- the conveyor belts control;
- the robot control;
- the holding device control;
- the vision control.

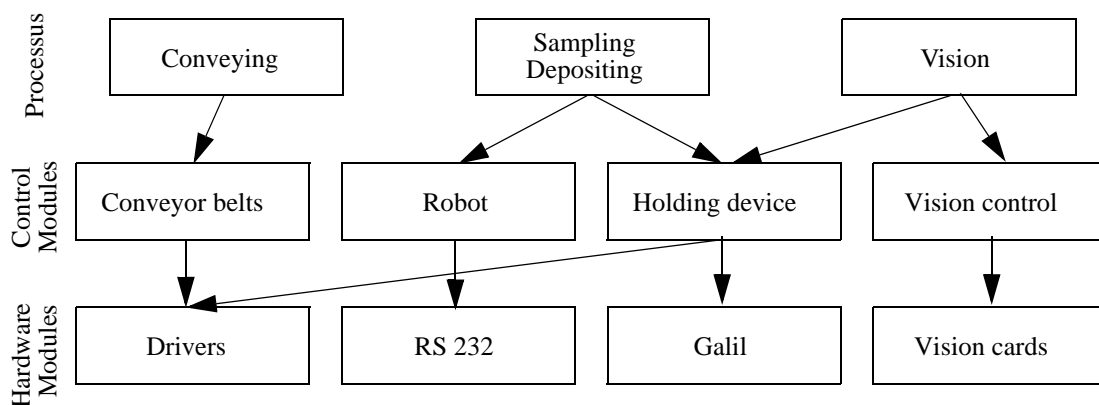


Figure 1: The software is organized into three layers. The arrows indicate the links between modules.

These modules may access more than one hardware module; for instance, the holding device module will access the “Galil module” (for the control of the holding device itself) and the “drivers module” (for the control of the rotation axis).

The last layer contains the three main process modules: the conveying module, the sampling and depositing module and the vision module. These modules have to work in time sharing.

Each of the layers described can only access a module defined in the next layer. As an example, the Vision Module cannot directly access vision cards but must go through the Vision Control Module.

2. MECHANICAL ROBOTIC SETUP

The mechanical robotic setup (Fig. 2) is composed of two main parts, corresponding to two of the processes described in the

previous section^{2,1,6}. The function of the first one is to bring potatoes to the holding device and to present them to the vision setup, while the second one proceeds to the pulp extraction and the depositing of the sample.

2.1 The conveying system

It is composed of three belts and a holding device. The purpose of the first belt (CB1) is to separate the potatoes from the bulk into small groups of at most 5 potatoes (Fig. 3). The presence of potatoes can be detected at the top of this belt. The second and third belts (respectively CB2 and CB3) are V-shaped (Fig. 4). They have three functions:

- to bring each potato from the bulk towards the holding system;
- to insure that each potato is singulated;
- to align the potatoes along their principal axis.

The first role is fulfilled by construction. The second function is warranted by the facts that CB3 has a greater speed than CB2 and by the use of presence detectors at the junction of both belts. The third function is insured by the V-shape of the belts.

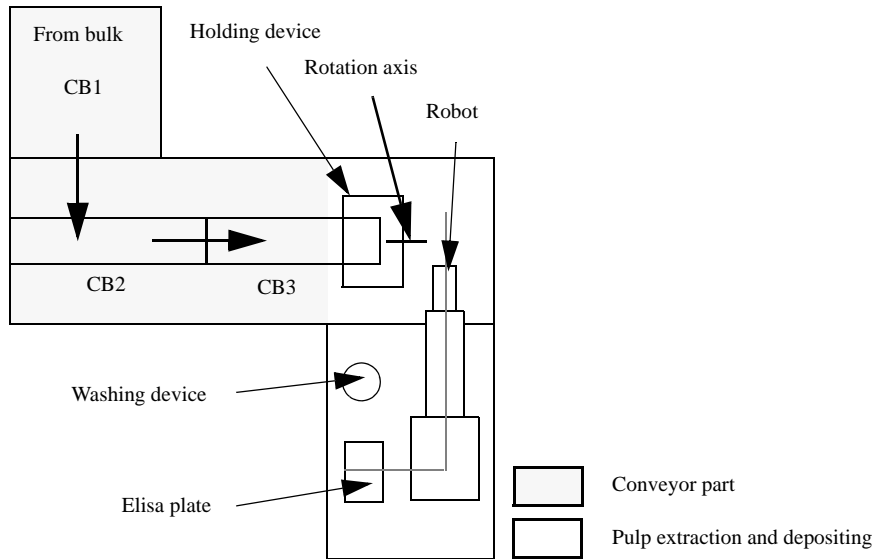


Figure 2: The robotic apparatus.

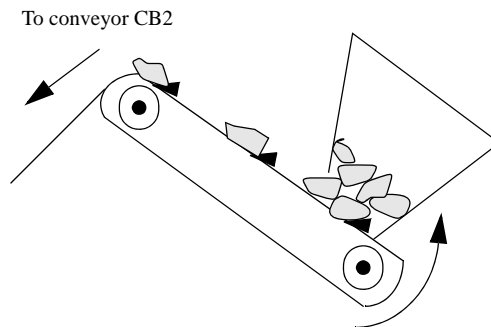


Figure 3: First conveyor (CB1), from bulk to a few potatoes.

2.2 The holding device

When the potato arrives at the end of the last roller belt, its size is estimated by means of a light sensor beam. The belt is then stopped, bringing the center of the potato under the holding device (Fig. 5). This device is then activated in order to bring the potato into the camera field of view.

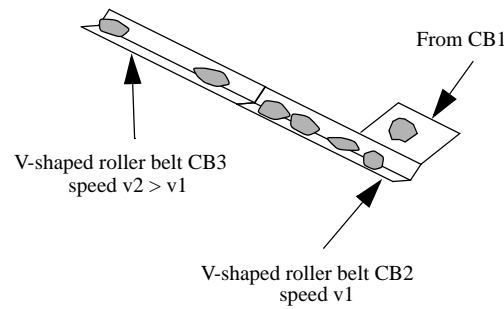


Figure 4: The V-shaped roller belts.

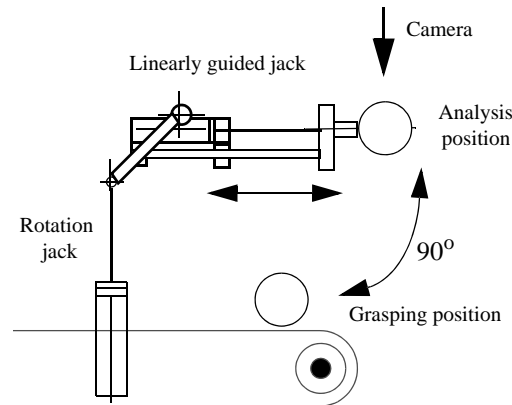


Figure 5: Holding device.

2.3 The robot and controller.

It has been shown² that a robot with at least 4 degrees of freedom is required to perform the pulp extraction. In order to avoid the limitations due to the four degrees of freedom, and to be able to use a commercial robot, we have finally selected a 5 degrees of freedom angular robot of type Mitsubishi RV-M1.

The robot uses the 3D information provided by the vision system to position the drilling machine along a normal to the sprout location. The robot then generates the trajectory required to drill a small hole under the sprout. When the target is reached, the Tecan pump is activated and some pulp is sampled. After the return trajectory has been generated and completed, the robot finally follows the trajectory required for the depositing and the cleaning of the drill.

The robot provides the required flexibility not only for the pulp extraction, which is a rather new robotic application, but also for the more conventional sample depositing and drill cleaning.

3. COMPUTER VISION

3.1 Grey level

This approach performs the 3D localization of the sprout by means of two images. The first one, so-called *profile image*, is used for the detection of the external protuberances (the sprouts and the device holding the potato). After selection of the largest sprout, the potato is rotated by 90° in order to bring this sprout in front of the camera, providing the second image called *frontal view*. By combining the information from these two complementary images, the 3D coordinates of the sprout are deduced (for details see e.g.⁵).

The first part of this method, that is the profile detection, is performed by the following steps:

- suppression of the image background;
- separation of the body of the potato from the external protuberances: morphological opening, then subtraction of the opened image from the original one;
- fitting of an ellipse onto the potato body, in order to furnish a good approximation of the penetration angle;

- separation of sprouts from artifacts: labelling of the regions followed by a selection of the best one based on criteria such as size or elongation;
- selection of the largest sprout, i.e. the largest amongst the remaining regions.

The potato is then rotated in order to bring the selected sprout in front of the camera. The frontal analysis consists of:

- suppression of the image background;
- extraction of the body of the potato by means of a morphological opening;
- sprouts location in the potato body by means of local variance extrema, where the local variance is computed in an $S \times S$ window. The choice of S is based on an estimation of sprouts size performed in the previous step (profile detection);
- identify the sprout that has been detected in the previous profile image, by the computation of the projection of the sprout position in the first image onto the next one.

The combination of the 2D coordinates of the detected sprout in the two complementary image leads to the 3D coordinates of the penetration point.

3.2 Fluorometry

Light can be generated by either one of two physical processes: incandescence (a thermal source generates the optical radiations) or luminescence (non-thermal excitation of atoms relying on changes of atoms energy caused by optical or chemical phenomenon). Luminescence can be either fluorescence or phosphorescence. It is important to notice that the optical wavelength of photons generated by fluorescence is always longer than the one of the incoming excitation light.

The idea of the fluorometry approach is to select an excitation source selective enough so that it will generate more fluorescence on sprouts tissues than on the body of the potato. With a fluorospectrometer, we have analyzed the best combination of excitation and reflection wavelengths on over 25 potato species⁹. For an excitation wavelength of 488 nm, we have obtained a fluorescent response of the sprout at 680 nm, thus showing that the fluorescence can be used for germ detection.

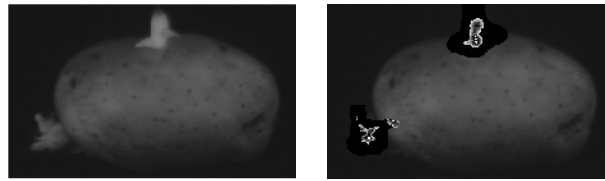


Figure 6: Detection with fluorometry.

To exploit this characteristic, controlled lighting and a camera sensitive in the near infrared (typically a CCD camera without infrared filter) have to be used. A first filter will suppress all emitted wavelengths that are not around the excitation wavelength (488 nm) while a second one, placed in front of the camera will be a band pass filter around the emission value (680 nm).

3.3 Infrared

Thermography allows to obtain a “thermal map” of an object. More precisely, each grey level of the image obtained corresponds to a temperature of the observed surface. The sensors of a thermal camera are sensitive to wavelengths in the far infrared (from 1 to 12 micrometers). These sensors work at very low temperatures, so they have to be cooled. Detecting the sprouts of a potato using such a device is accomplished by finding a temperature difference between the body and the sprouts. This difference does not normally exist and is therefore generated by blowing hot air onto the potato. Temperature increases more rapidly on the sprouts than on the body of the potato since sprouts are protuberant and smaller than the body. Thus a strong sprout/body contrast is generated in the thermal image. An example of such an image is given in Fig. 7.

Tests have been performed with an INFRAMETRICS 525 camera². With a simple thresholding, the sprouts can easily be detected as regions. This threshold is very easy to determine since the contrast between the sprouts and the body of the potato is very high. The contrast between the body and the background of the image is very low; it would nevertheless be possible, if required, to detect the contour of the body using a gradient operator.

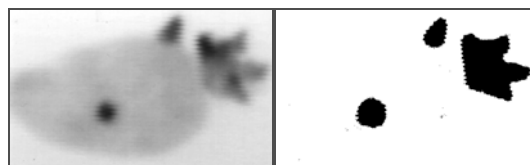


Figure 7: Detection of the sprouts using thermography.

Sprout detection by thermography is very fast and the vision processing is simple; sprouts cannot be confused with plaques on the surface of the potato and they can be detected even if they are very small. The main shortcoming of this method (to date) is the high price of infra-red sensors.

4. RESULTS AND DISCUSSION

4.1 Specialized hardware

All the vision algorithms have been first implemented on a Sun SparcStation1 in order to demonstrate their feasibility. Then, in order to speedup execution time and to have only one computer controlling the whole system (PC 486), a specialized hardware had to be used (Image 640 Matrox card). This allows us to execute most image processing tasks in real (or almost real) time. Table 1 gives examples of execution times in both configurations.

	Sun Station (seconds)	Matrox Card (seconds)
Threshold Histogram	10	1.2
Opening	4	0.2
Labelling	$10 < t < 20$	0.1
Loc. Variance	$40 < t < 80$	8

Table 1: Execution time comparison.

The whole specialized hardware is currently composed of three cards:

- the Matrox Image 640 Baseboard with a 640 x 480 display and 2M bytes of frame buffer;
- the Image-RTP that implements in hardware advanced image processing such as recursive morphology or fast labelling (at 15 MHz);
- the Image-CLD color digitizer;
- the Image-FPU application accelerator for compute-intensive tasks such as large kernel convolutions or FFTs (this module is factory installed on the baseboard).

4.2 Experiments

The whole process has been implemented, with some parts executed in time sharing (see Fig. 8). As an example, steps 3 (cleaning), 5 (sprout detection) and 6 (bringing of the next potato) are executed at the same time, since the robot records the position where it has to go and does not need anymore the intervention of the computer. The bringing of the potato is performed by interruption of the main program.

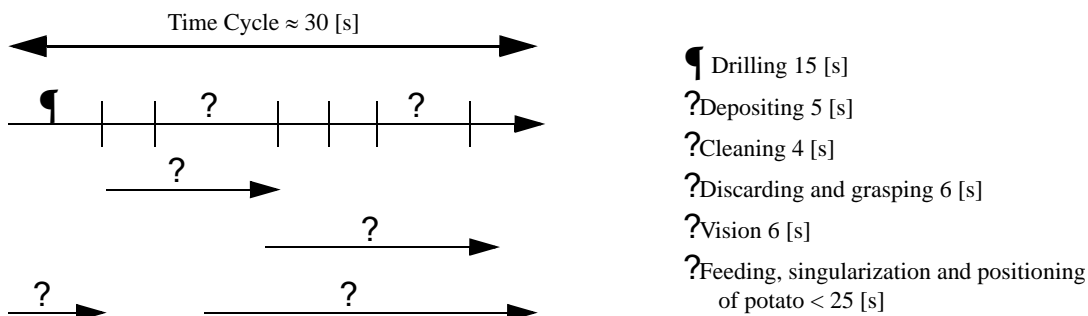


Figure 8: Time cycle description.

Two vision algorithms have been implemented. The first one combines a profile detection and a complementary sprout research based on fluorescence. The second one is based on fluorescence exclusively and combines two images corresponding

to an initial position of the potato and a view of the potato rotated by 90 degrees. The matching of one given sprout between its successive positions is performed by a prediction of its position from the initial to the last image.

	Agria Meth1 Meth2		Bintje Meth1 Meth2		Charlotte Meth1 Meth2		Eba Meth1 Meth2		Nicola Meth1 Meth2	
Mean sprout number	1.04		1.16		1.35		1.77		2.18	
Mean length (mm)	18		8		8		9		21	
Mean images number	2.24	2.48	2.51	3.14	2.31	2.23	2.30	2.18	2.62	2.83
Fluo. Contrast (0..10)	7.08		6.07		9.44		9.80		8.44	
Tubers furnished	99		235		50		101		85	
Tubers analysed	95		220		49		98		80	
Tubers sampled	68	70	130	106	49	44	87	83	44	36
Errors										
Error of holding device	4%		6%		2%		3%		5%	
Security stop	3%	3%	1%	3%	0%	2%	3%	6%	1%	4%
Imprecise drilling	0%	3%	4%	2%	2%	14%	0%	2%	2%	3%
Visual process error	6%	12%	5%	9%	8%	6%	4%	2%	4%	7%
Bad 3D matching	1%	0%	0%	0%	2%	2%	0%	0%	5%	0%
Sprout too long	1%	6%	21%	11%	10%	9%	1%	1%	18%	17%
Rejected potatoes										
No sprout	16%		21%		0%		1%		20%	
Sprout not detected	2%	5%	15%	23%	0%	0%	7%	2%	23%	26%
Due to vision	24%	21%	39%	44%	0%	2%	8%	3%	44%	46%
Due to robot	7%	9%	9%	14%	2%	8%	6%	12%	6%	14%
Total rejection rate	31%	29%	45%	55%	2%	10%	14%	15%	48%	58%

Table 2: Results obtained with two methods. The first one (meth1) is based on a profile analysis and a fluorescence detection. The second one (meth2) is based on fluorescence exclusively.

Table 2 gives some of the results obtained during the more recent series of experiments⁷. Here, five species of potatoes are presented and the following aspects of the machine have been measured:

- mean sprout number: mean number of sprouts per tuber;
- mean length: mean length of the sprouts per tuber;
- mean image number: mean number of images that need to be analyzed for detecting the sprouts;
- fluo. contrast: contrast between the sprout and the tuber skin in the fluorescence image; the human operator estimated this figure, with values lying between 0 (no contrast) and 10 (excellent contrast);
- tubers furnished: number of furnished potatoes;
- tubers analyzed: number of analyzed tubers (tubers that have not been rejected by the holding device);
- tubers sampled: number of sampling performed;
- error of holding device: the holding device missed the potato, no analysis has been performed (number of missed potatoes over number of furnished potatoes);
- security stop: the robot has not drilled in order to avoid damaging the holding device (number of security stop over

- number of analyzed potatoes);
- imprecise drilling: the drilling was not performed exactly under the detected sprout (number of imprecise drilling over number of drilling);
- visual process error: the sprout detection was wrong (number of bad detection over number of analyzed potatoes);
- bad 3D matching: the correspondence between the two complementary images was not accurate enough (number of bad matching over number of drilled potatoes);
- sprout too long: the sprout was too long for the visual system to detect the exact drilling place (number of too long sprouts over number of drilled potatoes).

During the experiments, no viral contamination between successive pulp samples have been observed, that is to say that none of the samplings was infected by a previous one.

Some work still has to be done to improve these results. Concerning the vision, we can observe that there is a strong correlation between the sprouts / tuber skin contrast, and the vision error rate. This contrast is proportional to the fluorescence re-emitted by the sprouts and is not constant in time. We have observed that we can enhance the fluorescence by appropriately choosing the time when the tubers have to be analyzed. For example, waiting some days after the potatoes have been taken out of the refrigerator usually increase the fluorescence. Sprouts that are too long can be avoided by a biological preparation of the potatoes, that is control of the sprout's growth by tuning the lighting intensity and the temperature in the refrigerator. The problems of 3D matching are usually caused by peculiar potato shapes, that are very different from the model we have chosen. This can be avoided by changing the angle of view during the visual analysis in order to acquire more than 2 images. Concerning the robotic apparatus, the holding device error can be decreased by adapting the V-shaped belt CB3 (Fig. 4), as this error is often due to the fact that a round potato rolls when the belt stops, thus preventing the holding device from grasping it. The security stops are due to the geometry of the system, when the robot refuses to drill in order to avoid touching and damaging the holding axis.

The feasibility of the project has been demonstrated and encouraging results have been obtained. But there is still some work to perform in order to reach a commercial prototype. Current developments concern optimizing the prehension procedure and defining a protocol for preparing the potatoes that would increase the fluorescence and the length of the sprouts.

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