Automated cutting of bovine carcass forequarters.

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Introduction

The main problem to solve for the success of the automated cutting process is to adapt the operations to the particular morphology of each forequarter. This can be divided into two problems. It is necessary: **1.** to adapt the characteristics of the different paths to each dimension of the quarter; **2.** to place correctly these paths on the carcass. Several methods can be envisaged:

· to perform a scene analysis on the totality of the carcass that allows, using image analysis, to build a path conform from a typical path.
· to construct a modelisation of each cutting path from previous experiences undertaken on a sufficient number of carcasses, and to implement, on each carcass, this path according to parameters measured on the carcass.

It is this last method that we have developed and have been able to implement. We have also defined simple method of actualization of paths from a judicious choice of the method and from reference points of paths.

"Primal cuts on the forequarter"

The last study that we have done concerns the realization of a prototype allowing the primal cuts in three traditional pieces of a forequarter of beef. We have used mostly the tools and methods developed in the previous study, to address herein the problems of the cutting of tissues including bones. We also tried to solve specific problems of the removal of tissue (notably piece movements during the action of tools), and have reached the limits that are possible to obtain with open loop automation techniques. It is necessary, if we want to work in such conditions, to envisage all possible scenarios, and to design in such a way that only an event known by advance could occur. The research concerning the holding of pieces has been a particularly delicate point because the restraint is here strongly linked to the action of tools.

The methodology of operations and the chronology of the different actions of tools, including the positioning of the mass of muscular tissue, has required many tests.

The holding system of the quarter insures functions of holding, positioning during cuts and withdrawal of the different cut pieces. This positioning system has to be synchronized with the movements of the robot because some actions of tools are combined with the holding of pieces to be separate.

The automation functions:

On order of the operator, the acquisition program implanted on a first computer starts up the acquisition of an image by the video camera, followed by processing, to calculate two parameters:

1. Calculation of the height of lifting of the quarter (hi) for a good station-keeping of the holding system. It has been obtained in two manners:
   · by research of the intersection point of planes from the previous cut of the half carcass in forequarter and hindquarter. But, in the case of a bad previous cut, the determination of this point can not permit a correct calculation of hi.
   · by research of a mark put on the vertebra corresponding to the 4th rib. This method allows a great reliability but requires a manual marking.
2. The parameter Dxy of gap of cutting path on the collar. This parameter is obtained by first calculating a partition of the surface of the quarter projected on the vertical plane YZ. The value of Dxy is deduced from this surface with the help of an experimentally established relationship. The value of lifting, hi, is directly transmitted to the programmable automaton. The value of the gap, Dxy, is transmitted to the computer that pilots the robot. This computer contains, in memory, a library of basic paths distributed in 3 groups 1, 11, and 111. Each group consist of 5 reference paths. The preparation of paths for each quarter has been made in two steps:

· choice of the group 1, 11 or 111 by a criterion of weight of the quarter (respectively inferior to 80 kg, ranged from 80 kg to 90 kg, superior to 90 kg).
The choice can, at times, be done on the weight of the carcass by taking for limits 340 kg and 375 kg.
· Shift of paths on the collar by a Dxy translation of the basic group of paths, in x and y directions of the robot referential.

After these adjustments, the paths of the group are associated with the various paths of service (plugs and deposits of tools) in order to build a complete carve-up program that is transmitted to the memory of the robot for execution.

Construction of the reference paths

The cut of the forequarter into three pieces is made by five cuss. (Fig. 2)

1. A first cut undertaken by a toothed circular saw transversely to the ribs, three centimetres parallel of the spinal column,
2. then a cut with a large knife on the high part of the neck along the shoulder,
3. a cut in the continuation until reaching the lend of the leg (in the case of large quarters),
4. a deep curving cut along the shoulder beside the caparison,
5. finally a last cut to dissociate the shoulder.

All these cuts have been built by successive adjustments on a great number of quarters (almost fifty), a particular cut being recorded for each quarter. The robot is piloted manually and guided in order to produce an ideal cut (the best if possible) for a given quarter. The conformation of a quarter is recorded similarly by the video system and our home-made 3D syntactic measure arm. If a quarter seems to have a similar conformation to a previously recorded quarter, the corresponding path is then executed by the robot in an automatic way. The gaps compared to the correct path are evaluated and a correction is then undertaken on the initial path that becomes the new model path .
We have thus built three groups of paths corresponding to each of three morphologies of carcass models.

Links between paths and models of morphology

At this stage each of the models of morphology corresponds to a group of path models. From the five paths of tools to undertake, four have to be modified, only the last path [5] is an average path that fits in all cases. The path of cutting ribs [1] is physically linked to the path [4]. The bottom trace of the circular saw corresponds to the bottom of the cut described by the tip of the knife, the two cuts being approximately perpendicular to each other. Any displacement for adjustment on one of these two cuts has to be undertaken the same way as the other. We apply therefore the same adjustments to [1] and [4]. After several tests, it has been proven that a couple of paths was sufficient and that only a binary choice was necessary. The criterion of choice of the couple of paths is strongly linked to the weight of the quarter; it has been fixed to 90 kg. In this same way cuts [2] and [3] beside the collar are physically linked, the path [3] being the continuation of the path [2]. The path of the bottom [3] is applied only for the heaviest fore quarters (superiors to 80 kg). It has been established during tests that only an adjustment by modification of cuts in a direction was necessary. After statistical study, correlations have been established between the change to undertake on the position of paths and a surface situated at the bottom of the neck of the quarter. A measure of this surface done automatically by the video system allows to calculate this adjustment. The parameters of readjustment have constantly been refined in comparison with the result of the cutting operation and in regard of the result expected. Measures of geometry on a great number of forequarters, with the 3D syntactic measure system that we have developed in our laboratory, have established the previous relationships allowing modification and adaptation of paths models previously defined. These path models are distributed in two classes. Each class is representative of an obvious type of bovines. This allows us to minimise gaps between the calculated path and the ideal path. A video system takes the acquisition from particular points allowing an automatic

positioning of the quarter on the holding frame system.
From this video image analysis the parameters of path corrections are calculated.
The "large cuts" or primal cuts allow separation of the fore quarter into three pieces: the shoulder, the caparison, the neck / bottom ribs. This operation is undertaken by a succession of cuts and automated manipulations of pieces to be broken. The first cutting operation is sawing with a circular electric saw. All operations are strung together automatically (automatic positioning of the quarter, service paths of tools, automatic tool change, positioning of masses to separate, actions of cutting and withdrawal of pieces).
In the current state of the prototype, the complete cycle is 2mn 45s and the effective action of tools needs 45s.
Some considerations and remarks: Several observations from these experiments are summarised:; - The very strong interdependence between many parameters ; * flexion of the blade / flexion of the frame system / deformations of the quarter; * path of cut / effort of cut / deformation of quarter
* speed of wrench / effort of wrench / preliminary cut ; * criteria of choice of the type of tools / different situations met.
- The necessity to use anatomical fixings well defined, especially in the case of pieces to be maintained during and after the separation.
- The technical limit of the utilization of automation in open loop imposing a complete knowledge of the evolution of the process of deboning (as a result implying the multiplicity of tests). It is necessary to increase the precision of paths in order to improve the reliability of operations and especially the yield for more complex muscles to be extract. The residual variability obtained on models shows the necessary introduction in the system of a correction of the path undertaken in dynamic form from local data. These have to be provided in real time by a sensor able to detect the approach of a typical bone / muscle interface.
Such a sensor does not exist today but the study of feasibility is underway and its industrial development anticipated in a annexe project of research carried on at the Station de Recherches sur la Viande (4)(5). Conditions of breaking the carcass with an automatic system have to focus on the same objectives as the manual dismantlement. It should be stressed that the method used to separate a muscle or a piece can be very different from that used by the butcher, inasmuch as notions of fatigue and force do not take place whereas those of speed and especially dexterity are here more critical.
Finally, it was apparent very clearly in our experiments that the method of dismantlement and tools are closely linked. A method is able to be exploited only if the necessary well implemented tools exist and reciprocally, a tool can be exploited successfully only by a well adapted method.
Considering these reflections and the success of the previous project, we work now, in a project started in the frame of an EUREKA European project (KU 1032 "ABCD"), on the realization of an industrial prototype. This project sustained by INTERBEV, with participation of the I.N.R.A, is realised with the company DURAND INTERNATIONAL. The objective is, from a half - carcass, to separate the fore quarter from the rear quarter, and with a further machine, to remove muscles or groups of muscles from the fore quarter. The first equipment is under development and should be established by the beginning of 1998.

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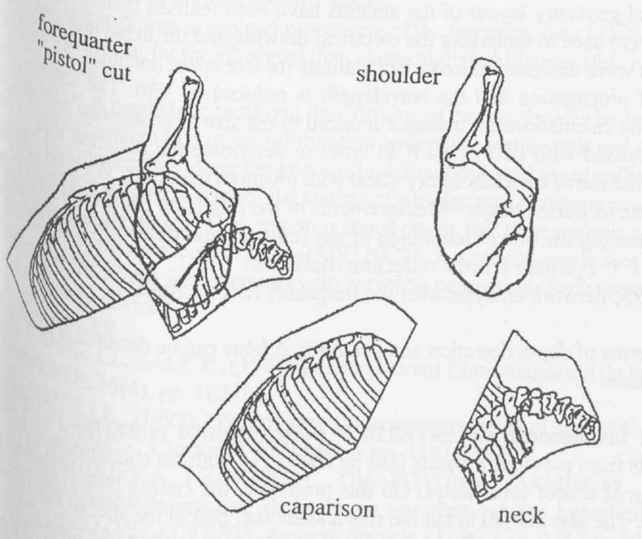

Figure 1 Primal cut of forequarter

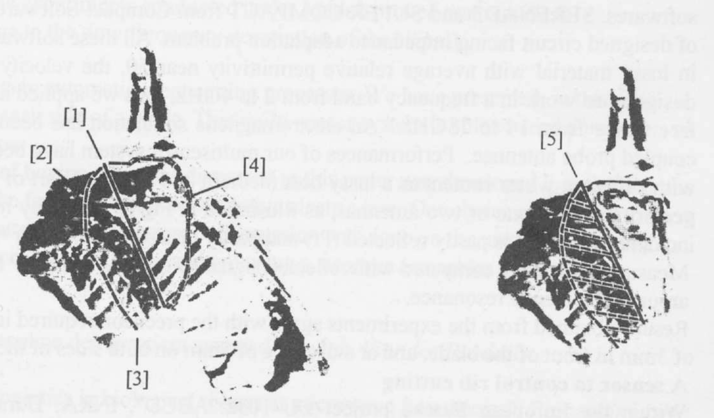

Fig.2 Cutting path positions on the fore quarter