AUTOMATIC EXTRACTION OF A MUSCLE FROM A BEEF FOREQUARTER

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SUMMARY

An automatic computer controlled dismantlement of beef carcass was carried out on hot meat with an adaptation of the tools trajectories to the specific geometry of each carcass. We will discuss beef carcass modelling and paths fitting. A strategy for dismantlement of different muscles was set up and the complete operation on the *supra spinatus* muscle performed by an electric robot with 6 axes equipped with three different tools, and a computer for trajectories calculations and robot paths controls.

1 - INTRODUCTION

Many problems encountered in the meat industry result from a poor efficiency of the economic and technological methods. The aim of cattle slaughtering, from stunning to chilling and boning is to extract the meat from the body of animals. These operations are dismantling operations which are to be performed on the basis of the anatomical organisation of the body.

Today, these dismantlement operations are done manually by butchers. In the future theses operation will be done by automated systems allowing more economical and hygienic work. FUTUTECH developed in Australia for the slaughter line is a first step of this evolution.

In our laboratory we work on the automation of the boning process of beef carcasses. In a preliminary study we identified the main problems which are to be solved in an automatic boning system. They are related to positioning the carcass, use of specials tools, and adaptations of the paths of the tools to the specific shape of each carcass. There also appears a very high degree of interaction between these different points

For this work we restrict our objective to removing one muscle from the forequarter within the following specifications :

- not any manual operation;
- respect of the current usage of the butchery that is the respect of the anatomic structure ;
- work done in hot boning conditions, less than two hours post-mortem.

This condition which will prevail in the future allows the use of non conventional methods for split muscle from bones such as stretching. Theses methods, not usable in manual boning are useful for an automated work when they are substituted with very accurate and complex cutting actions.

2 - EXPERIMENTAL EQUIPMENT

The experimental equipment was designed mainly for research purposes and components were chosen rather for their technical performances than for their convenience to an industrial context. The system is composed of the following parts (fig 1):

a-) The holding system (fig 2) is a metallic rectangular frame equipped with five fastening points. Four of them could be moved to the dimensions of each quarter. The frame can rotate around a vertical axis and is mechanically bounded to the robot .

b-) Two 3D measurement systems are available

A manual device made with four articulate rods. The relative angular position of the rods are measured with a computerised system and the tip point co-ordinate is calculated and stored each 0.1 sec. By scanning the quarter surface with the tip-point the co-ordinates of 3000 points randomly distributed on the surface are measured on each quarter.

A video system developed at the University of Clermont-Ferrand can be used for co-ordinates acquisition of points located on 15 vertical sections drowned by light planes. This device was designed for a fast recognition of quarter based on specific shape identification of a section and can be used in an industrial environment.

c-) Different specialised tools. Three tools were necessary to remove the *infra-spinatus:*

- a steel blade with a symmetric shape looking like a lis flower is used to cut muscles and aponevrosis;
- an electric reciprocating knife whose frequency is remote controlled. It has a curved blade. and is used for cutting tendons;

- Pneumatic pliers with special prongs used to grip tendons and pull out the muscle. The pulling force can reach 200 kg and a complex mechanism was necessary to obtain a proper grip on the warm tendon.

d-) a mechanism able to move the tools under the computer control. It is an electric robot with 6 axis able to apply forces up to 200 kg, a model commonly used in mechanical industry. It is equipped with a pneumatic system allowing the automatic tool change, with an interface board and fully controlled by a computer;

e-) a computer system used for data acquisition, 3D measurements, modelling calculations, path tools adaptation and robot control. A set of software was written in C and Pascal languages, for all theses applications. All machines are at IBM-PC/AT standard.

3 - SETTING A STRATEGY FOR THE EXTRACTION OF THE MUSCLE

There are many different possibilities to remove a muscle from the carcass. The method used by a butcher is a compromise solution between his dexterity to a knife with minimum tire and his strength. The butcher's method cannot be copied by a machine because of the complexity of the movements. With a mechanical system we can use more heavy tools and apply important forces but the motions of these tools have to be simple. The first step is to decide how to remove the muscle, (with cuts only or with cuts and by pulling out the muscle), where the cuts are to be done, what tools are to be used , in what order the different operations are done.

Then each operation is executed, with the robot in manual mode configuration and moving step by step. At the same time the co-ordinates of the significant points of the path are recorded. Next the path for each tool is executed with the robot in automatic mode and can be fitted to produce a more efficient result.

After a lot of experiments, we obtained a set of trajectories, each defined by the co-ordinates of a specific point of the tool (for instance the tip of the knife) and the value of the quaternion which define the 4 angles giving the orientation of the tool in the space. Moreover parameters for the robot such as the speed and the accuracy of the displacement are given.

In the case of the *infra spinatus* muscle, the set of trajectories comprises 4 trajectories as defined on the figure 3. All these trajectories are strongly linked for their mutual position. The experience shows that in the situation where we work, this set of trajectories could be applied to any quarter, in a large game of scale within the following conditions:

1- The proper location of one point of these trajectories is deciding for a successful operation. This "main point" is numbered #2 on figure 2. The position of this point on the quarter must be located with an error less than 10 mm measured from anatomic points of the quarter. Unfortunately, these anatomic points (i. e. the extremal part of the scapula apophisis) are not all located at the surface and cannot be directly extracted from an image of the quarter. When the right position of the main point is found, only a translation of all the points is needed to obtains a proper position of the whole set of trajectories.

2- The angular position of this set must be fitted for each quarter by applying rotations of the whole set around two axis. The first axis is a vertical axis and the second an horizontal axis perpendicular to the sagital plane of the quarter. The two axis cross at the main point.

These conditions are not absolutes. They are the expression of specifications of the equipment and tools such as blade compliance, or pliers dimensions, and signifies the importance of these characteristics on the settling of the strategy of muscle dismantlement.

4 - PUTTING THE SET OF TRAJECTORIES ON THE QUARTER

To implement properly the muscle extraction, the knowledge of the main point co-ordinates on the quarter are necessary. The anatomic and consequently the quarter geometric organisation can be defined as a common organisation. The different anatomical parts are always arranged following a general scheme which define the shape, the geometrics dimensions and the relative position of each anatomical element. This scheme is invariable for different animals from the same specie. But for an animal the geometry of items differ from the general scheme by size shape and location. We tried to calculate the main point by the measurement of lengths and distances between points easily takes on the quarter.

Two methods were tested: modelling and correlation.

A.) Modelling:

A model of external surface of the quarter was built. The successive steps of this construction were:

1) the random distributed points given by the 3D manual system were reorganised so that the projection of the points on the vertical plane (yz plane) was on a regular grid of 1x1 cm,

2) the co-ordinate system is linked to the quarter using specific points such as the centre of gravity for the origin of the new co-ordinate system,

3) the three co-ordinates of each point are normalised using the references length which can be easily measured on the quarter,

4) the model is obtained from the mean values of normalised co-ordinates.

Three models were built from 55 quarters whose geometric dimensions ranges as shown in table 1. The calculation of the mean value of the differences between the real point and its homologue position calculated with the model gives an evaluation of the concordance between the quarter and the model. Results shown in figure 4 indicate that for the best case of the tested models, only 15% of the quarter give a deviation < 10 mm. This poor result may be explained as consequence of the large degree of freedom allowed to the shoulder which cannot be immobilised by tightening the leg .

To improve the accuracy of the model, we split the set of quarters in two groups on the basis of the error with the former model. But the result was unsatisfactory and it appears that differences between the quarter and the model result more from a randomly distributed local fluctuation than from a global deformation of the quarter. Moreover if we look at the algebraic difference between the quarter and the model then that difference is lower than 10 mm for 87% of the quarters.

Table 1

parameters	minimum	maximum	unit
weigh	39	65	kg
area	0.35	0.46	m²
mean thickness	0.14	0.17	m
L	0.42	0.53	m
H	0.69	0.81	m
Lref	0.40	0.45	m

B.) Correlation:

When an automatic execution with the robot succeeds, we have the correct co-ordinate of the main point in the working conditions of the robot. For 29 of these quarters we have also measured all the 33 parameters used for the model building. The statistical analysis of these data indicates significant relations only for the X and Y co-ordinates of the main point. They could be calculated using a linear regression.

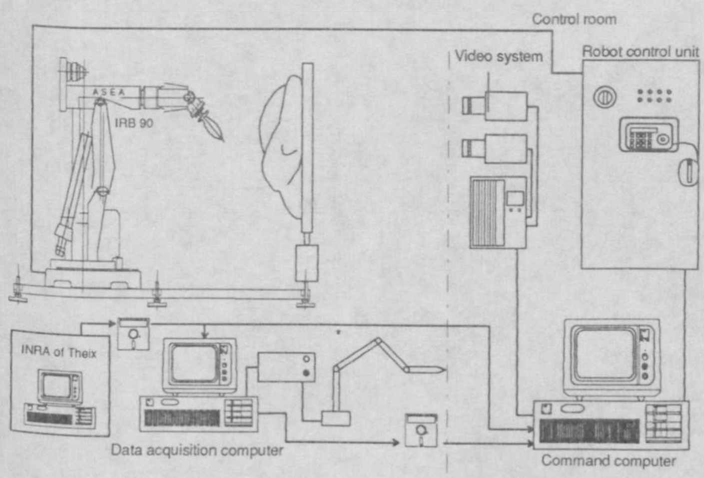

Figure 1 : Experimental equipment

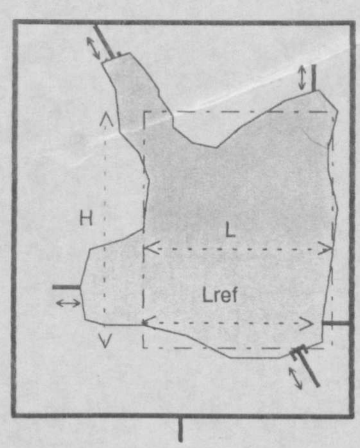

Figure 2 : The holding system

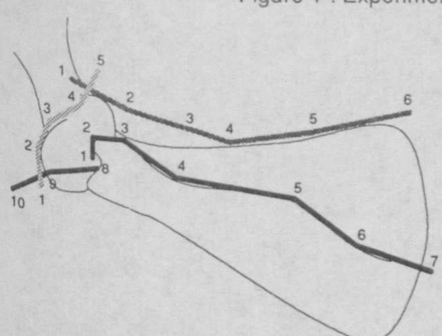

Figure 3 : Cutting paths on the scapular

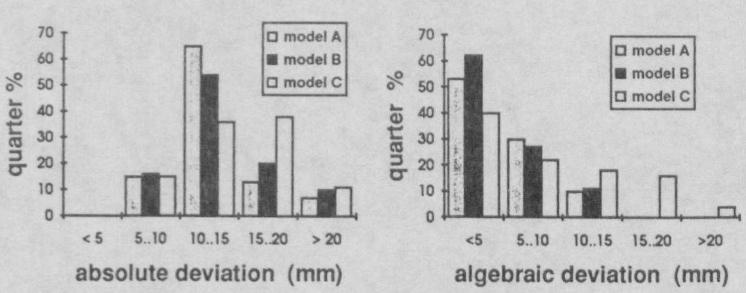

Figure 4 : Deviations from models

The standard error on the remainder were respectively of 7 and 17 mm. No significant relation was found for the Y co-ordinate. We observed that the y axis direction is the direction where the free movement of the shoulder is easier.

Direct measurement of the main point:

We have measured the co-ordinates of two points needed to correct the set of trajectories. We used the 3D manual device equipped with a needle as a sensitive end.. This needle was stuck into the meat at a controlled depth for the main point and stuck to the bone surface for the auxiliary point. Theses co-ordinates were then used to calculate the translation and the rotations applied to the set of trajectories before it is transferred to the robot. We succeeded to perform the complete extraction of the muscle with the robot with this method .

CONCLUSION

This work demonstrates the feasibility of an automatic muscle removing from a quarter. It gives a more realistic evaluation of the problems we have to solve before such an operation could be used in an industrial workshop. This work was done in hot boning situation so pulling out the muscle was possible. This needs only scarce cutting operations and allows the use of a restricted set of cutting trajectories. However the calculation of the proper position of the main point failed mainly because of the poor quarter rigidity.

The robot was driven by an open loop command and no information generated during the operation was used. This is a high speed method (its take 40 seconds of working time to remove the muscle in our conditions), but needs a perfect fit of the trajectories to the worked quarter to succeed. Moreover it is very difficult to reach the level of success needed for an industrial application. The use of '"intelligent tools" (see J.L. DAMEZ's paper) witch are able to perform a short distance detection between different tissues will put right the local discrepancies between calculate and real trajectories and made the automatic boning a reality .

Acknowledgement

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