PS3.07 Strategies for robotization of beef carcass primal cutting 378.00

Grégory Guire (1) guire@ifma.fr, Eric Lemoine(2), Franck Stephan 3, Laurent Sabourin 4 Grigoré Gogu 5
(1)LAMI- Université Blaise Pascal
(2)ADIV
(3)LASMEA- Université Blaise Pascal
(4)LAMI- Université Blaise Pascal LAMI- Université Blaise Pascal

Abstract— The food industry is increasingly moving towards mechanized or robotic solutions to solve labor shortages. This study focuses on the robotization of beef quartering, with the objective of defining new cutting and deboning processes. The main challenge is to obtain a robotization of cutting and deboning tasks that respect all constraints and which is adapted to all types of carcasses. These constraints are either related to health standard issues or are specific to French working methods to carry out anatomical cuts. Adapting 'theoretical' cuts to different types of carcasses is difficult due to the large variability of beef carcasses. The conclusions presented in this short paper result from a series of cutting tests with the robot cell and several tools to validate the feasibility of such complex tasks. The use of a robot with force control and a rib counting system allowed us to partially overcome the carcass variability.

Guire G., Sabourin L. and Gogu G. are with the Laboratoire de Mechanique et Ingénieries (LaMI EA 3867–FR TIMS/CNRS 2856), Campus de Clermont-Ferrand, 63175 Aubière, France, phone: +33473288006, fax: +33473288027, e-mail: author@ifma.fr Lemoine E. is with the Meat Technology Department, ADIV, 10 rue Jacqueline, ZAC des Gravanches, 63039 Clermont-Ferrand Cedex 2, France, phone: +33473985380, fax: +33473985385, e-mail: eric.lemoine@adiv.fr Stephan F. is with the Laboratoire des Sciences et Matériaux pour l'Electronique et d'Automatique (LASMEA – UMR 6602 UBP/CNRS), Campus des Cézeaux, 63177 Aubière Cedex, France, phone: +33473407256, fax: +33473407262, e-mail: franck.stephan@lasmea.univ-bpclermont.fr

Index Terms—deboning, meat cutting, process constraints, robotization.

I. INTRODUCTION

The mechanization and robotization of meat processing operations has became, over the past few years, a crucial challenge for companies working on meat transformation and in the meat and meat products sector. This sector is the largest in the AFI (Agro and Food Industries) in terms of employment (122,049 employees in 2005) and sales (31.1 billion Euros in 2005) in France. The mechanization of this under-automated sector could help us tackle some of the challenges and threats that companies working in the meat sector are currently facing, such as:

- labor shortages,
- dangerous and strenuous work involved,
- competition from meat exported from countries with low labor costs.

Today, companies working in meat activities, and especially in the slaughtering-quartering sector, are having increasing difficulties in finding qualified labor. This loss of interest in the meat sector by skilled workers and young people is mainly due to a devalued image of the job, difficult work conditions (unsociable working hours, cold temperatures, etc…) and the strenuous work involved (repetitive tasks, heavy loads to carry and handle, etc…) [1].

Therefore, companies are faced with a disparity between hired unskilled workers and the qualifications that are necessary to carry out meat quartering tasks. This problem has a large impact on productivity and consequently on the companies' profitability. The mechanization of these jobs has therefore become an important objective for companies looking to improve the safety and health of workers in this sector, as well as finding new solutions concerning the increasing production costs linked to current and future labor shortages.

The mechanization and robotization in the slaughtering and quartering sector have increased during the last decade, mainly for pork [2] and ovine [3] processing. However, there has been less work carried out in beef slaughtering and quartering due to the large variability of bovine carcasses which necessitates the use of more accurate and adaptable technologies. Furthermore, beef meat consumer habits in France which favor steaks and roasts, also add strong restrictions in terms of beef deboning and cutting. Indeed, these constraints imply that cutting and deboning actions have to be performed with respect to the muscle's anatomy in order to valorize them as high quality cuts. This approach fundamentally modifies the requirements and the automation techniques that need to be developed, and increases the challenges related to beef anatomical quartering robotization.

The work presented in this short paper focuses on the robotization of beef carcass primal cutting (the first operation in the beef quartering process) which has been identified by French companies as the priority task to be automated. This work is part of a French national program (SRDViand) which also deals with the robotization of forequarter cutting and deboning.

The final objective of the project is to perform a fully automated and autonomous beef carcass primal cutting operation without any human intervention. This short paper studies the technical feasibility of the different cuts implicated in the primal cutting operation. The project's next step will be to test a vision-based acquisition device which enables the robotic system to adapt to any type of carcass by taking into account the large variability of bovine carcasses.

II. MATERIALS AND METHODS

The methodology used to test the technical feasibility of robotized beef carcass primal cutting was to carry out a complete and precise analysis of manual work performed by operators at industrial level. We observed working practices in French slaughterhouses as well as carrying out numerous manual tests with skilled butchers in ADIV's pilot plant in order to study and analyze the different manual tasks. This analysis led us to precisely define the characteristic points and the cutting path, identify the constraints, redefine the cutting strategy to be used with a robotic approach and select the appropriate tools. Validation tests of the technical feasibility of beef carcass primal cutting were carried out with a prototype robotic cell implemented in the ADIV agro food pilot plant (Fig. 1).

Figure 1: Robotic cell installed in the ADIV agro food pilot plant. A. Studied operation The studied beef carcass primal cut is a specific cut called 'Z-cut', which follows specific anatomical points on the carcass and leads to a forequarter with 5 ribs (AVT5) and a hindquarter with 8 ribs (ART8). The detail of anatomical points and the different cuts is illustrated in Fig. 2.

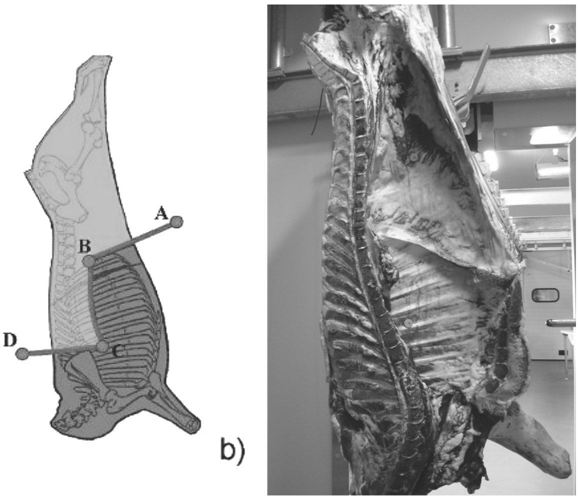

Figure 2: Anatomical points and cuts indentified in the 'Z-cut' primal cut.

This 'Z-cut' process combines 3 different cuts:

- a cut along the 13th rib (cut A-B) in which the point B is located just upper the 13th rib and around 10 cm from the vertebral column. Both this point and point A on the flank of the carcass have to be defined very accurately in order to preserve the integrity of the hindquarter and particularly not to cut into the Transversus abdominis, a high quality muscle.
- a cut through the ribs (cut B-C) between the 5th and the 13th ribs with a constant distance from the vertebra column. This cut

necessitates the 8 ribs to be cut accurately, without any leeway on the number of ribs cut.

- a cut through the vertebra column (cut C-D) at the level of the 5th rib.

B. Constraints on the cutting process The beef carcass primal cutting has to be carried out in accordance with some sanitary (BSE) and quality requirements (no residual part of bones or cartilages in the meat, no cuts inside muscles, etc…).

The 3 cuts involved in the beef carcass primal cutting bring to light several constraints in the robotization process:

- dimensional variability: size, shape, conformation, etc…
- textual variability: fat, texture, etc…
- misshapenness of the carcass during cutting,
- accuracy of cuts needed to preserve the integrity of muscles.

This implies the accurate identification of the anatomical characteristic points and also controlling the correct number of ribs cut. The cutting actions are complex tasks on deformable material with a large dimensional variability. To perform such complex tasks, the operator combines both vision, haptic perception and force feedback.

The automation of these tasks requires the integration of exteroceptive vision-based and force-based sensors:

- vision is used to readapt the cutting trajectories in the working area [4],
- force control is used to adjust locally a theoretical trajectory with the real object [5], [6], [7], [8].

C. Definition of these new process Because of the complexity of manual operations, it was necessary to redefine the cutting and deboning processes. The associated constraints impact the cutting quality, the production rates, the causes of nonconformities and workflow integration. For each operation, the technical studies carried out enabled, through the search for new working methods, the translation of operations in robotic tasks. This was done in close collaboration with meat industry companies and an applied research institute specialized in the meat sector, and partners of the SRDViand project. The establishment of the new process requires the characterization of the cutting strategy (trajectory, tool, cutting conditions), the definition of carcass restraint system, studying the geometry of pieces of meat and their variability, defining exteroceptive sensors and data analysis, defining the type of control (vision, force control, hybrid vision/force control), and finally defining the structural parameters and the workspace of the cell.

D. Materials

1) Tools A state of the art of potentially usable tools for cutting meat and bone was performed. After conducting preliminary tests, some technologies were excluded for health or technical reasons (poor quality of cut): laser, water jet, ultrasonic blade, etc…

Finally, the tools which were selected and tested included several types of knives (with several blade profiles), several types of saws (circular, alternative, or jigsaws) and a dedicated system such as hydraulic shear.

2) Robot Due to the task complexity, the choice of the robot architecture has covered an anthropomorphic robot arm with six degree of freedom [9], [10], [11]. Furthermore, to solve the problem of carcass variability carcasses, this robot is equipped with an integrated force control.

III. RESULTS AND DISCUSSION

Based on the analysis of manual work by operators at industrial level, the strategy for the robotization of beef carcass primal cutting ('Z-cut') combines 3 cutting actions (Fig. 2):

- cut along the 13th rib,
- cut between the 5th and the 13th rib,
- cut through the vertebra column on the 5th rib.

For each cut, the most appropriate technologies were selected in accordance with the identified constraints:

- counting system for the rib cut (8 ribs to be cut between the 5th and the 13th),
- force control for the cut along the 13th rib in contact with the bone.

Several tests were performed to study the technical feasibility of the 3 cuts implicated in beef carcass primal cutting.

A. Cut between the 5th and 13th ribs The 8 rib cut is performed with an electrical jigsaw (Fig. 3).

The rib counting system developed is able to count the exact number of cut ribs. This will allow the cut to be stopped precisely at the anatomical points in carcass between the 5th and the 6th ribs (point C) and above the 13th rib (point B). Figure 3: Cut between the 5th and the 13th ribs with an electrical jigsaw.

B. Cut along the 13th rib In order to respect the anatomy of muscles and therefore preserve the integrity of high value hindquarter muscles, this cut has to performed as closely as possible to the 13th rib with the right direction and angle. This cut is performed automatically from point B to point A with a knife (Fig. 4).

The force control device allows for the detection of the rib by the tool and adapts the cutting trajectory to perform a cut in contact with the rib. The orientation and the angle of the tools are maintained during the cut into the flank. This system avoids the use of any other sensors or acquisition devices to perform this precise cut.

Cut in contact with the 13th rib with a knife controlled by a force control device. Concerning the technical feasibility, the 2 major technological issues have been addressed. Indeed, the counting system for cut ribs has been validated and the robot is able to perform cuts in contact with bones. The technical feasibility has been tested on a targeted sample of carcasses and has to be validated on a larger carcass sample which takes into account the large variability of carcasses (breed, size, conformation, fatness, etc…).

IV. CONCLUSION

The strategy for performing robotized beef carcass primal cutting has been established and adapted from manual working procedures. Some scientific and technical issues have been identified and associated with the selected cutting strategy. The work presented here validates two main technical functions of the system. Future work will focus on the integration of all the different elements needed for a fully automated cut including the integration of a vision-based system to take into account the carcass variability and the optimization of the robot control.

ACKNOWLEDGEMENTS

This study was carried out thanks to the support of the French Ministry of Industry, France Agrimer and the Auvergne, Bretagne and Rhône-Alpes regions. This project is labeled by Innoviandes, the French meat competitive cluster.

REFERENCES

[1] CNAMTS (2004), Statistiques nationales des accidents du travail, des accidents de trajet et des maladies professionnelles-Année 2002, Caisse Nationale d'Assurance Maladie des Travailleurs salariés, Paris, France, pp 548.

[2] Purnell G. (1998), Robotic equipment in the meat industry, Meat Science, Vol. 49, Supplement 1, pp. S297-S307.

[3] Aimers R. (2003), Animal carcass leg removal method and apparatus, International Publication Number WO 03/096814 A1.

[4] Mezouar Y., Prats M., Martinet M. (2007), External Hybrid Vision/Force control., In International Conference on Advanced Robotics, Jeju, Korea, pp. 170-175.

[5] Duchemin G., Dombre E., Pierrot F., Poignet Ph. (2002), Robotized Skin Harvesting , 8th Int. Symp. On Experimental Robotics, Sant'Angello D'Ischia, Italy, paper 30.

[6] De Schutter J., Bruyninckx H., and Spong. M.W. (1997), Force control: a bird's eye view. IEEE CSS/RAS International Workshop on "Control Problems in Robotics and Automation: Future Directions", San Diego, CA, USA.

[7] Liu J., Zhang Y., Tian Z. (2004), Neuromaster: A robot System for Neurosurgery, Proc. Of the 2004 IEEE International Conference on Robotics & Automation, New Orleans, LA, p.824-828.

[8] Pierrot F., Dombre E., Dégoulange E., Urbain L., Caron P, Boudet S., Gariépy J., Mégnien J. (1999), Hippocrate : a safe

robot arm for medical application with force feedback, Medical Image Analysis, vol. 3, n°3, p. 285-300.

[9] Gogu. G. (2002), Families of 6R orthogonal robotic manipulator with only isolated and pseudo-isolated singularities, Mechanism and machine theorie, Vol 37, pp. 1347-1375.

[10] Gogu G., Barraco A., Coiffet P. (1997), Représentation des déplacements des robots, Paris, Hermes, ISBN 2-86601-572-X.

[11] Wenger M. (2002), Analyse et modélisation des robots manipulateurs, sous la direction d'Etienne Dombre, Paris, Hermes Science, chapitre N°5, ISBN 2-7462-0300-6