A robotic cell for pork legs deboning

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***Abstract*— Nowadays, companies in the meat-cutting sector are encountering increasing difficulties and the mechanization/robotization of their processes has become essential to improve the security, the health and the working conditions. The presentation deals with pork legs deboning, a primary task carried out within the framework of the SRDViand project. The first part involves in-depth study of operators' expertise, so as to translate their actions into automated operative tasks and to identify the robotics constraints. The second part details more particularly a cutting strategy dealing with the bone tracking which shows the complexity of the process. The third part presents a kinematically redundant robotized cell to improve the accessibility of the task and the constraints associated to the redundancy resolution. The results are very encouraging. This study is in partnership with ADIV, two research laboratories at the Blaise Pascal University, the LaMI and the LASMEA, and industrial companies.**

***Keywords* — Robotic, pork legs, deboning.**

I. INTRODUCTION

Nowadays, companies in the meat sector, particularly the cutting sector, are encountering increasing difficulty in recruiting experienced staff. These difficulties are mainly due to working conditions (cold temperature, unsociable hours, dangerousness and painfulness) causing a high rate of musculoskeletal accidents [1]. Automation of these jobs becomes a key objective to enhance productivity, safety and operator health and to ensure the production method. Moreover, firms face strong competition of products from MERCOSUR (Argentina, Brazil, Paraguay and Uruguay) countries with cheap labor, or countries that have already started some robotic operations such as Denmark (DMRI), Japan (MAYEKAWA) or New Zealand (MIRINZ) [2]. Purnell highlights the challenges of integrating robotics in the food industry and the scientific obstacles to achieve [3].

The work presented is included in framework of the SRDViand project (FUI). It is carried by ADIV (Technical Center for the Meat Industry) and in partnership with two research laboratories at the Blaise Pascal University, LaMI and LASMEA, and two companies (designer for slaughtering, cutting and processing meat industry). Two operations are concerned by the program: quartering of beef carcasses [4] and pork legs deboning. They are considered by the industrial sector as the primary tasks to robotise. In this paper, we are only discussing about the process of pork legs deboning.

II. CONTEXT AND APPLICATION

First, we present the manual process and the tasks leading to a robotization. We detail the objectives, constraints and strategies related to more or less complex one. The preliminary step is to retrieve the bone of the hip (Fig. 1a) from the skinless pork leg.

A. Anatomic cutting of pork leg deboning

This task consists in opening the pork leg (muscles) to the bone along the aponeurosis (tissue which separates the muscles). The operator visually marks the 2nd fat vein (Fig. 1a) (separation made of fatty tissue and aponeurosis). He follows the aponeurosis while he is guided by the bone. Cuts along the tibia are similar (Fig. 1b). The next step is the bone extraction (tibia, femur and patella) from the pork leg (Fig. 1c). So, the operator makes some successive cuts along each bone. The last operation permits to cut the tendons and tissues that still connect the meat (Fig. 1d).

B. Process constraints

A set of constraints is associated with the process operations:

- Textural variability: even if the pork legs are calibrated, the fat percentage and texture can change according to the animal and meat aging.
- Deformation during the task: applied forces and the links separation between the meat and bones imply a pork leg distortion. That requires self-adaptation pathways.
- Bone identification: bone identification is disrupted by the flexibility of the link between the femur and the tibia.
- Discontinuous cuttings: operator uses small incision gestures.
- Heterogeneity: a pork leg is composed of a

superposition of heterogeneous meat, bones, fatty tissues, blood stripe, etc... This aspect greatly disturbs the tracking of feature points for cutting paths.

- Sensory coupling: the operator uses a permanent coupling between the vision and the effort or sensation he feels.

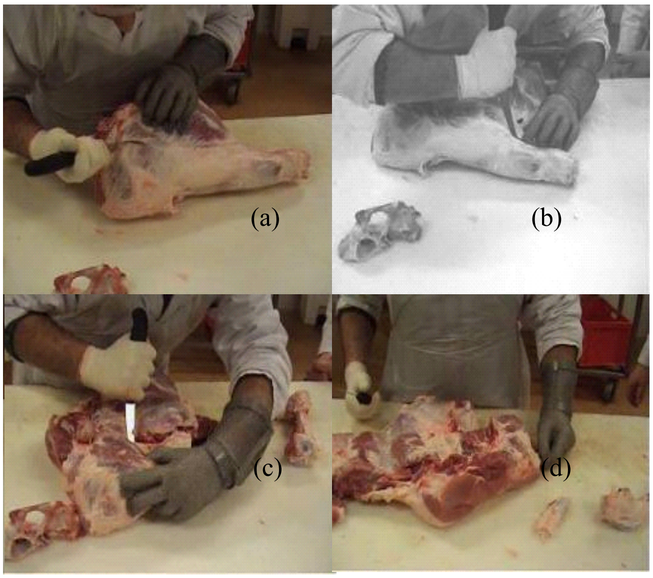

Fig.1 Steps of the manual procedure: 1. opening the 2nd fat vein (a), 2. cutting along the tibia (b), 3. extraction of the femur (c), 4. removal of the patella (d).

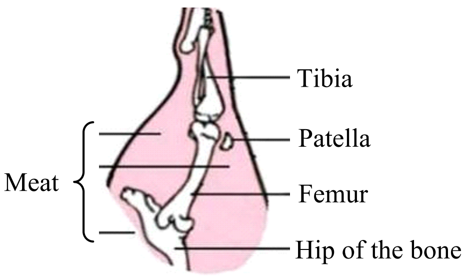

Fig.2 Pork leg composition

The described manual cutting operations are complex and applied on a deformable body, with dimensional variability. The operator must use different signals, mainly the vision, tactile identification and effort sensation.

C. Task overview

Due to the various and complex operations, we have redefined with ADIV specialists, the whole process of pork leg deboning. Because of the difficulty to identify by vision the different components (bones, veins), we based the cutting strategy on the use of force control to adapt the theoretical path to the real one [5]. The overview realized on the pork leg permitted to define basic operations. In the rest of the paper we will develop the most complex ones: cutting task along bones.

D. Cutting task along a bone

The cut is constrained by a set of parameters related to the blade, its movement and position, relative to the bone with a contact force. The number of features is important and we used a classification method [6] to identify key parameters: the cutting angle α, the feed rate speed V_f, the speed V_n normal at V_f. These parameters adjustment are affecting the cutting quality (straight cut, bone chips or cartilage). A number of cutting principle modelling exists. The work focuses primarily on the reduction of the cutting forces. They concern the cutting angle α [7][8] or the blade shape [9]. They show for example that when the cutting angle α is less than 30°, the forces are reduced by 30%. The objective is to guarantee the cutting quality and minimize the efforts to minimize pork leg deformation during the various cuts. The set of parameters α, V_f, V_n and F_c (Fig. 3) are used to define their areas of variability and their relative importance on the cutting quality. The results obtained confirm the influence of the couple α/V_n on the F_c force and the cutting quality. Finally, to ensure the cutting quality and to reduce cutting forces, it is important to have a cutting angle α close to 30 ° or a non-zero component V_n combined with V_f.

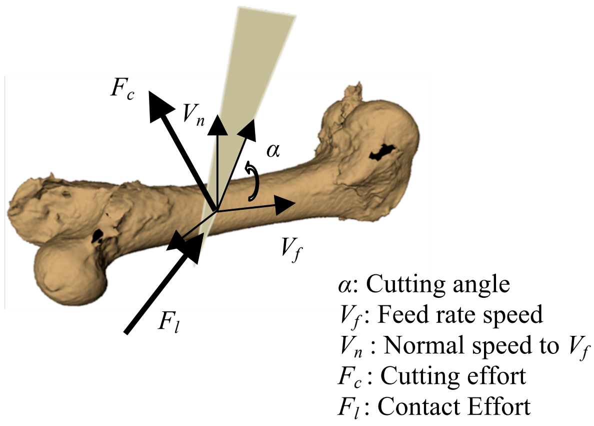

Fig.3 Set of cutting parameters on a bone

III. ROBOTIC CELL

The choice of the robotic cell depends on the study of different processes which makes necessary to determine: the characteristics and task boundaries (volume, accessibility, etc...), the most appropriate placement of the robot relative to the task (or vice versa), the feasible path and the optimized one over a set of criteria.

A set of paths has been defined taking into account the dimensions variability of a maximum of potential pork legs. Most operations require an incision around the bones which requires the integration of a controlled external axis. Based on an iterative process, the study has permitted to determine the best position of the various components of the cell: robot, external axis, etc... (Fig. 4).

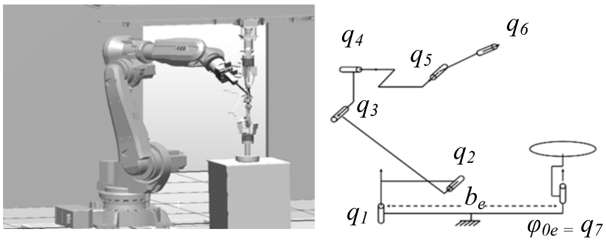

Fig.4 The robotic cell and its kinematic architecture

A. Robotic cell with external axis

Geometric modelling is necessary for simulation and optimization. We made a TCS model (Travelling Coordinate System) [4] [10] (Fig. 4). The external axis adds a variable joint φ_{0e}. The resolution of the new direct geometrical model is directly in series with the addition of this axis. The relative position of this axis is described by an additional architectural parameter b_e that must also be included in the model.

B. Force control, process constraints

One objective of our work is to ensure the achievement of various operations on partially known trajectories, due to the variability of pork leg dimensions [11] and mainly to improve the overall kinematic behaviour of the cell to ensure the cutting quality. Theoretical trajectories are first programmed and then repositioned through the force control [12], allowing the robot to overcome its position and to respond spontaneously to the efforts it feels.

The kinematic redundancy management needs to introduce additional criteria in the selection of solutions to ensure the path parcourability [13].

C. Solving method

Solving the problem consists in determining for each set of the path, the parameter q_7 of the turntable. The first optimization criteria are related to the removal of singularities, joint stops and q_s parcourability trajectories. We also define a stiffness criterion (minimizing cantilever robot):

$$c_r = min\left|q_2 + q_3\right| \qquad (1)$$

The final criterion impacts more specifically on the dexterity improvement in the advancing direction u_f defined by [14]:

$$c_f = u_f^T (JJ^T) u_f \qquad (2)$$

We are in the case of a multi-objective optimization. To resolve the redundancy [15], a classical method is the use of the projection onto the kernel of the Jacobian matrix J:

$$\dot{q} = J^+ \dot{x} + \underbrace{(I - J^+ J)}_{J_h} z \qquad (3)$$

with $J^+ = J^T(JJ^T)^{-1}$ means the pseudo inverse of J, z is a vector of same dimension as q, I is the identity matrix (of dimension q) J_h and the projection matrix of z on the kernel of J. The vector z in this case is defined as the gradient of an objective function $C(q)$ constructed by aggregating the original objectives. One of the difficulties of aggregation methods is the choice of the weight assigned to each criterion. To change the relative importance of each criterion, we use a method with variable weights [16]. The form of the objective function C becomes:

$$C(q) = \sum_{i=1}^{k} w_i\left(\bar{c}_i(x)\right)\bar{c}_i(q) \text{ with } \bar{c}_i(q) = \frac{c_i(q) - c_{i\min}}{c_{i\max} - c_{i\min}} \qquad (4)$$

With $w_i\left(\bar{c}_i(q)\right)$ the weight function dependant to $\bar{c}_i$ which varies from 0 to 1.

The simulation tool and optimization is developed in Matlab® used in complement with RobotStudio®, allowing to define and to validate our own criteria [4][17]. Fig. 5 shows the posture of the robot for a given trajectory without (a, c) and with optimization (b, d). The images (a, b) illustrate the criterion for singularity removal, (c, d) the stiffness criterion limiting the movement of q_2 and q_3 axis robot.

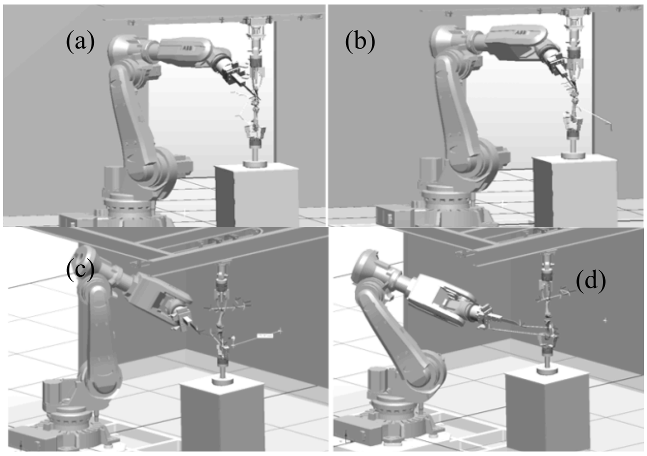

Fig.5 Non optimized posture (a,c) – Optimized posture (b,d)

IV. INDUSTRIAL RESULTS

The actual results for robotic pork legs deboning are very encouraging for further developments and to validate the strategy in terms of cutting quality and bones/muscles separation.

A study is being conducted to compare the performance of a horizontal manual deboning (on table) and a deboning using the turntable axis with a vertical holding of the pork leg.

V. CONCLUSION

The work presented in this paper refers to the automation of pork legs deboning complex tasks. After describing the operations carried out manually, we present a process resulting from the investigation of new working methods and the constraints.

We describe more particularly the cutting strategy on a bone which requires a force control related to the high path variability. We present the model associated with the redundant cell then the formalization of the problem of redundancy management and the optimization criteria used (stiffness, parcourability, dexterity in a direction, etc..).

Optimization is applied to the various operations to improve the behaviour of the cell. The current work concerns the definition of new criteria related to cutting quality.

The results will increase the capacity of the cell in terms of adaptation to the task and thus can evolve into more complex operations.

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