FEASIBILITY STUDY USING ROBOTICS FOR BONING PORK LOINS

N. Lay, J. Neugebauer, R. D. Schraft - Fraunhofer-Institut für Produktionstechnik und Automatisierung (IPA) - Germany
S. Herlevsen, K. Persson, L. Svensson - Swedish Meat Research Institute (SMRI) - Sweden

ABSTRACT

Today the meat processing industry is significantly affected by high and increasing labour costs and staff shortage due to unattractive cold and humid working environment with ergonomic constraints. In order to keep this industry on a high level of competition on a long-term basis and ensuring high meat quality, the application of more high technology in general and specially in flexible automation will be required. Automated meat cutting and boning will be one of the key items for meat processing technology in the future. At the Fraunhofer Institut für Produktionstechnik und Automatisierung, Stuttgart, in co-operation with the Swedish Meat Research Institute, Kävlinge, a feasibility study of a new method for automatic boning of pork loins with robots is worked out employing Virtual Reality technology in the developing, programming and testing phase. Using different sensor systems like computer vision and tactile feedback sensors the bones in the loin can be detected. Employing advanced simulation technique like Virtual Reality complex cutting processes can be simulated in order to reduce the developing time of a real robot cell. At IPA a real robot workcell and the simulation of these robot cell in Virtual Reality has been implemented for further development.

MOTIVATION

Considering the constantly increasing demand for meat products in connection with the high quality requirements and the strict hygienic standards the modern meat processing industry faces the need to discover and exhaust further rationalisation potentials.

Economical aspects and current Working Conditions in the Meat Processing Industry

The ergonomically and climatically bad working conditions result in a large number of staff away sick and represent unattractive jobs on the labour market, which leads to a high fluctuation in staff and a decreasing number of applicants. Moreover due to these extremely inhuman working conditions in the cutting/boning field, only few people can work in this area until their retirement. In comparison to other branches of industry the meat processing industry is one of the worst industries regarding illness statistics. The poor statistics are basically affected by the two areas of work - slaughtering and cutting/boning. The typical illness (92% - 95%) of this occupational group is wear out damage which significantly is caused by short cycle times, hard physical work, extremely high working speed and last but not least a cold and humid working environment. Therefore and because of the high staffing requirements for cutting and boning, the use of new automation technology becomes absolutely necessary in this branch of industry.

REQUIREMENTS FOR THE ROBOT WORKCELL

Since the boned meat achieves the highest market value the economical conclusion is to minimise the meat remaining on the bones. On the other hand bone splinter residues in the meat are unacceptable, which means the cutting process has to be performed very precisely and sensitively. In addition to this a robot workcell has to meet the hygienic requirements of the food processing industry. All parts directly or indirectly in contact with meat have to be designed to be easily dismantled, cleaned and sterilised when required.

PROBLEMS DUE TO MATERIAL CHARACTERISTICS

Each loin has an individual geometric structure and orientation of the bones. This biological characteristic of the flexible workpiece, which furthermore consists of inhomogeneous material, presents a technical challenge for automation until today. A further obstacle for flexible automation in the meat processing industry, especially in the boning process, is the increasing instability of the loins during the processing. The detection and recognition of the individual loin shape is one of the most important technical demands on an automatic boning process.

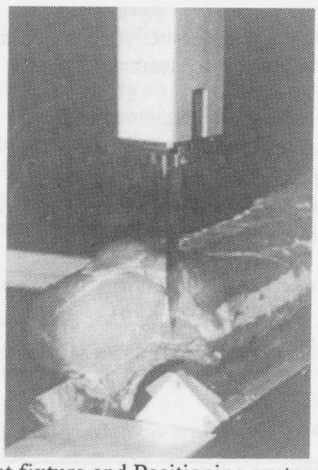
COMPONENTS

Aligning Device

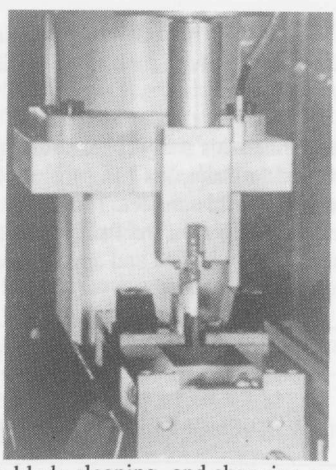
Since the cut in half vertebras show a 90° cutting edge they are particularly suitable for fixing the loins. Therefore it is the ideal interface between an anatomic and flexible loin and the exact geometry of technical equipment. The variable lengths of ribs and the undefined position and orientation of the vertebra therefore have no effect on gripping and fastening the loins. The position and orientation of loins regarding the grasping system are kept continuously until the cut is finished. The possibility of bending the loins is ruled out. A fixing of right and left loins is possible. During the cutting process collisions of cutting tool and fixing system and damaging of loins are avoided. The loins can be fastened and removed easily.

Cutting Tool

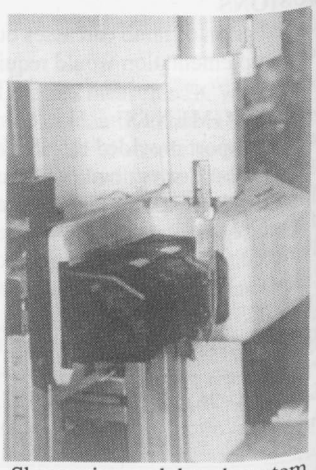
A straight oscillating knife for the automatic cutting was created based on the manual cutting tool designed by 'Giesser Messer' , Germany.



Meat fixture and Positioning system



Knife blade cleaning- and changing system



Sharpening and detach system

Figure 1: Straight oscillating knife for automatic cutting

The cutting tool consists of five basic components: Force feedback sensors, a system for compensating tolerances, a hydraulic drive system and a knife change unit and knife blades. Figure 1 shows the different process steps performed by the cutting tool unit. The hydraulic drive generates an oscillation of the knife blade at a frequency 50 Hz and an amplitude of 4 mm. The main advantage using this type of drive is the favourable relation of performance, compactness, weight, low noise emissions and vibration. The change of the knife blade is implemented in a quick-change-system which supplies several different types of knife blades. Depending on the cutting task, different types of knife blades can be chosen. In order to keep a high hygienic standard and to avoid cross contamination the quick-change-system is equipped with an automatic sterilising devise. To maintain a high cutting quality, it is necessary to sharpen the blades between the single cutting process. For this purpose an automatic knife blade sharpener is provided. A system for compensating tolerances combined with tactile sensors facilitates the possibility of adjusting to biological variations in the meat products and therefore an optimal cutting path.

FINDING OF CUTTING PATH

The automatic following of the cutting path has been developed out of the manual cutting process. The aim is a sequence of movements suitable for automation with a minimum of meat remaining on the bones, the shortest possible cycle times and avoiding secondary operations.
The first cut of the oscillating knife separates the meat from the diagonal processes of the spine. The second cut separates the meat from the spinous processes. The third cut runs along the ribs and the fourth cut runs along the ribs and the vertebra. For each cut a change of loin orientation is necessary. This can be realised in two ways. On the one hand the loin can be rotated on an axis which is parallel to the vertebra. On the other hand the orientation of the knife can be changed. While the loin is rotating the orientation of the knife is kept constantly vertical. The angle of the aligning device is changed corresponding to the cutting path and must also be adapted to the geometry of each loin.

Grey-Scale-Imaging

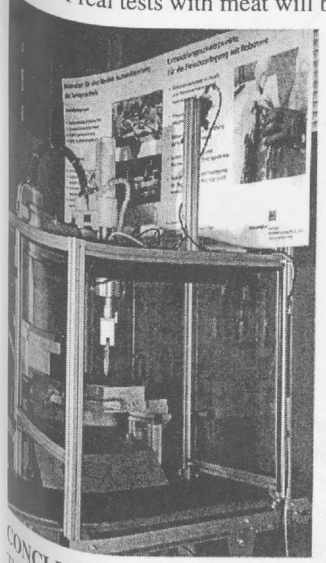
The analysis of methods for the determination of starting points and cutting paths has shown, that grey scale image processing is the most suitable for measuring shape and orientation of loins and for estimating starting points and cutting paths. Apart from economical aspects especially the processing time is an important advantage of grey-scale image processing. In the worked out method the loin is illuminated by neon light and three two-dimensional grey scale images are taken from three different viewpoints, which correspond to the Cartesian co-ordinate levels. With the appropriate illumination the contours of the loins can be detected and measured reliably. A relatively high image processing speed (4 seconds) for the recording and evaluation of the grey scale images is guaranteed. This process is technologically matured. CCD-cameras with relatively small dimensions can be purchased inexpensively from different manufacturers. Standardised image processing systems and software tools for image analysis are also offered. The outside contour of the loin is extracted from the grey scale images. Based on the extracted outside contour significant image points are detected with an arithmetic morphology, which represent the starting points and the rough cutting path.

CONTROL OF CUTTING PROCESS USING FUZZY-LOGIC-TECHNOLOGY

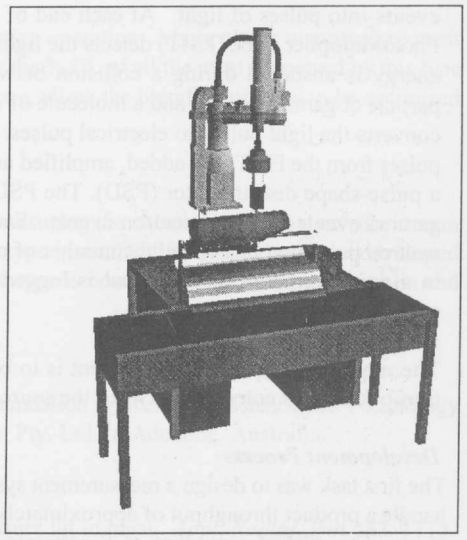
The biological characteristic of loins, which occurs increasingly with the separation of muscles and tendons while cutting, demands detecting position and orientation of the bones with a sensor in order to enable a permanent adaptation of the cutting path by superimposed correction movements during the cutting progress. Influencing forces on the cutting tools during cutting are detected with three force sensors. In addition to that a sensor in the cutting tool notes changes of cutting parameters in the tools. All sensor signals are sent to a controller. The evaluated output-signal is transferred to the robot control which controls the cutting movements of the robot. Especially for such problems, which on the one hand are very difficult to be formulated mathematically and on the other hand can be described very precisely using the concrete expert knowledge, fuzzy-logic-controllers are the best suitable. Joining the fuzzy controller characteristics with self-learning processes, a mighty tool for designing complex adaptive control systems, is obtained.

VIRTUAL PROTOTYPE

A virtual prototype of a loin cutting workcell has been designed and modelled. The virtual prototype has most of the characteristics of the real robot workcell. The three-dimensional impression of the simulation makes the observer forgetting that he is in a simulation. The VR-simulation is direct connected to the robot control system, so that the simulation can be carried out in the loop. This offers the possibility of developing a fuzzy-cutting-path-controller within the VR environment and a test system for the controllers in the real system. Therefore the number of real tests with meat will be reduced thus saving time and meat products during the developing process.



Real robot workcell



Virtual robot workcell

CONCLUSION AND ACKNOWLEDGEMENTS

This feasibility study has shown, that the implementation of new technology in the meat processing industry is as well necessary as possible.
The research and development work was achieved by a team lead by Dipl.-Ing. Norbert Lay, Fraunhofer-Institut für Produktionstechnik und Automatisierung (IPA) in Stuttgart, which is one of Europe's leading research institutes in the field of production development and automation. The project was initialised by Steen Herlevsen; B.Sc. Production Eng., the Swedish Meat Research Institute in Kävlinge, Sweden. The production manager of the meat cutting, Kenneth Persson within Scan HB, participated actively in the project.