AUTOMATIC SEPARATION OF MEAT PRODUCTS

CROOKS D.A. and KHODABANDEHLOO K.

Advanced Manufacturing and Automation Research Centre (AMARC), University of Bristol, Bristol, United Kingdom.

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SUMMARY

The meat processing industry has a need for adaptable machines capable of tasks currently performed by skilled butchers. Typical applications are evisceration, deboning and primal-cutting, the main task in these cases is the separation of flexible, non-homogeneous materials. This paper demonstrates an approach to the separation process which should enable automatic systems to be developed which meet industry requirements for accuracy, quality, safety and reliablity and are economically viable.

Circular-saw cutting was chosen as a representative process for development. Test equipment has been constructed to examine cutting forces. The objectives were to establish optimum cutter blade speed and power demands, to determine the required cutter manipulation forces over a range of feed speeds, and to develop a cut monitoring method which can detect errors. Results collected for a particular combination of blade and meat show that, over the range tested, there is an approximately linear increase of cutting force with feed speed but there is no change in cutting force with blade speed, the optimum blade speed being defined by cut quality. Use of an off-line signal processing method has shown the feasibility of detecting cut errors.

Introduction

Automated butchery systems have been a subject for research for many years (Khodabandehloo, 1993, Chapter 1). A system using robotic technology for meat separation must be capable of achieving the same end results (or products) as those systems employing skilled butchers. Manual butchery involves the handling and manipulation of the product and cutting tools to achieve correctly defined cuts. The process also requires real time interpretation of features that allow correct cuts to be defined. The cutting is controlled through the manipulation and sensing capabilities of the human butcher. If the total process is to be automated then technological developments must produce systems capable of achieving equivalent capabilities or skills.

A number of research projects have examined the basic approaches for automating meat processing. Figure 1 shows the main elements of an automatic separation system of the type considered by research to date. Aspects of image interpretation, decision processing and adaptive manipulation have been key subjects for investigation. The main focus of this research is complementary and is concerned with the actual process of separation, this is where the main physical interaction of an automatic separation system with the meat product occurs.

There are several requirements for knowledge of the separation process. The optimum cutter blade speed and power is needed to design a cutter which can perform cuts at the required speed and quality. The forces generated by separation must be delivered by the manipulator and resisted by the handling system, knowledge of these forces is needed to enable economic design. A method of error detection is needed to allow safe, reliable operation without the need for excess human supervision, a suitable method of error detection would be real-time processing of force data.

Background

The work follows an AFRC (no. LRG-114) funded project which investigated the deboning of beef forequarters (Khodabandehloo, 1993, Chapter 5) and is linked to two Brite-EuRam projects which deal with the primary processing of pork (Brite-EuRam 4152, 4420). The three projects have a common main task, automatic separation of a meat product into two, or more, pieces. The case of circular saw cutting of meat was chosen as a representative example process. Little evidence of study of the separation area has been found in reviews of automation of meat processing (Khodabandehloo, 1993, Longdell, 1993, Paardekooper et al. 1994). The automatic sheep-shearing system work was last reported as being in the process of improving the cutting tool design, but no tests are mentioned (Trevelyan, 1992). A mathematical approach has been sought by some (Ivashov et al. 1985) but the results appear to be process specific.

A review of separation technologies was made to establish how different methods might be suited to automation, the main conclusion was that powered saws were most appropriate for use with current technologies. Unpowered knives and saws require an additional degree of manipulation to achieve the cutting action, this greatly increases the complexity of the manipulator path. Water jet and laser cutting tools do not generate significant cutting forces, this prevents force monitoring of cut progress, they are expensive technologies and cut quality can be a problem.

A distinction was made between cutting and peeling operations, figure 2 shows how the basic processes are considered to be fundamentally different in operation, though the results may be very similar. The research work is not intended to cover peeling processes.

Methods and Materials

A series of tests was performed in an initial exploration of the cutting forces, test equipment was constructed to perform tests over a range of feed speeds and blade speeds on a defined sample. The sample section was chosen to contain several types of tissue including muscle, bone and fat. The area considered was the area of ribs parallel to the spine, beef, lamb or pork could be used. This paper deals with a set of data collected from tests on pork samples. The specimen was prepared with the ribs running at right-angles to the cut direction, the approximate sample dimensions were 300 mm length, 200 mm width and 65 mm depth.

The test equipment was developed to enable tests to be conducted under consistent cutting conditions, figure 3 shows a schematic plan of the rig. The main design features are that it provides for consistent cutting conditions over a range of feed speeds (0 to 200 mm/sec) and blade rotaional speeds (0 to 6000 rev/min), and can accurately record cut position, cutting forces, feed speed, blade rotational speed and blade drive torque. Feed-axis position and speed is controlled and measured by a servomotor and tacho system. Forces are measured by a strain-gauged plate which supports the blade bearings, a universal joint in the driveshaft is arranged at the centre of flexure of the support plate so that no bending moment is resisted by the drive motor. Torque and blade speed are determined by the blade drive control unit from the frequency and current in two of the supply phases, the unit also monitors blade speed and position with a motor-encoder unit. The test procedure is controlled by the control computer's program. All tests were photographed and video-taped. The cut is inspected for quality, in particular for the amount of sawdust produced, surface condition, sharp or chipped bone edges, and coloration due to heat effects. Ambient air temperature and sample surface and core temperature are recorded.

Results

A set of 50 tests on similar samples was considered for this initial analysis. The following parameters were recorded or determined for each test; material, carcass weight, core temperature, ambient temperature, post-mortem storage, cut length, feed speed, blade speed, up/down cutting, sample rate, maximum x-force (absolute), maximum y-force, feed energy, blade energy, average x-force, average y-force and cut quality. Four parameters were calculated from the force data set, feed energy is evaluated as the sum of the products of x-force data and distance moved per sample. The blade energy is evaluated as the sum of the products of resultant blade force acting tangentially to blade edge and blade rotational speed and the average x-force and average y-force are evaluated as the sum of x- or y-force data divided by the number of samples over the length of cut.

Discussion

From inspection of plots of test force data it was noted that maximum forces did not vary with blade rotational speed, but the amplitude of the force variation when cutting ribs tended to decrease with increasing blade speed, typically, peak-to-peak, 75 N at 1000 rev/min and 50 N at 2000 rev/min. The main effect of blade speed changes was the cut quality, this dictated low and high blade speed limits. The low limit was defined where bones were broken rather than cut. The high limit was defined where blade friction caused heat damage to the cut surfaces, this damage was visible as a change in colour of the cut surface and by the smell produced.

The test data was examined for any apparent trends. No trends were noted for variation of measured parameters with blade speed, for maximum cut force there was an even scatter of data over the blade speed range tested. Cutting forces increased with feed speed and there is an approximately linear relationship between the two.

There is a general characteristic shape for the force plots for all the test cuts. The variation of cutting forces through the cut may be separated into three stages, introduction, mid-cut and clearing, figure 4 illustrates these. Stage 1 covers the **introduction** of blade into cut, x-force increases as a greater length of blade engages in cut, this peaks as the first rib is cut by leading edge. Y-force increases to a peak which is the combination of cutting force component and friction forces on the upward moving part of the blade. Stage 2, the **mid-cut**, is where a steady state is reached, maximum x-force is reached with full cut depth, clear peaks as each rib is cut (8 in total). Y-force decreases as friction on upward and downward moving parts of blade balance, the y-force at this point should only be from cutting. Stage 3, the blade is **clearing** the cut, the x-force decreases as the blade completes the cut, no rib peaks. Y-force reaches a positive peak due to friction force on downward moving part of blade.

This interpretation allows other parameters to be determined from the force data in order to describe the cut. The additional parameters considered are rib-peak x-force amplitude, average stage 2 x-force, stage 1 y-force peak, stage 2 y-force average and stage 3 y-force peak. Because there is a regular form to the ribs and blade out of roundness a signal processing method, Fast Fourier Transforms (FFT's), was chosen to analyse the data .

The analysis was applied to typical x-force data, figure 5 shows an example output. The left "cut" peak's frequency is determined by the time to perform the cut and the amplitude by the average cutting force. The centre "rib" peak's frequency is determined by the feed speed and the rib spacing and the amplitude is determined by the force variation for cutting the ribs and by the number of ribs. The right "blade" peak's frequency is determined by the rotational speed of the blade and the amplitude by the eccentricity of the blade.

If the cut varies from the normal then the amplitude, frequency and number of the peaks changes, this provides a basis for a method of cut monitoring. In a test where the sample moved in the fixture a second cut peak occured and three smaller rib peaks were produced. Blade eccentricity changes would cause the amplitude of the cut peak to change and speed changes would cause the frequency to alter. If a fault in the blade circumference occured, such as a missing tooth, then multiple higher frequency "blade" peaks would be produced, the frequencies would depend on the spacing between the faults, and the amplitude would depend on the severity of the fault.

The analysis of this set of results shows that the optimum blade speed needs to be determined dependant on the required cut quality, the feed speed is linked to cutting force and that signal analysis can be used to monitor cutting. It should be possible to develop the force signal processing to give a real time monitoring method.

There are some limitations to the scope of the tests presented here. The feed speed of the current rig is limited and higher feed speeds would seem to be possible with the current combination of blade and sample. The effects of post-mortem storage and carcass variations have not been examined, in the tests a consistent method of preparation was used. It is expected that peak forces will not change significantly with storage because they occur when cutting bone, the properties of which do not change with storage. Cutting forces are expected to increase with carcass weight according to bone cross-section increases with weight. The effect of gradual blade wear has not been assessed, it is expected that the proposed monitoring system would detect the change as a force amplitude increase, possibly of all the peaks, a limit of force where cut quality becomes unacceptable is expected, this may be determined from testing with worn blades.

Conclusions

The aim of the paper was to present an approach to the study of the separation process based on the needs of automatic separation systems. These needs are for knowledge of the relationships between cutting force, blade speed and feed speed and for a method of monitoring cut progress. Circular-saw cutting was chosen as an example process and test equipment was constructed to measure cut forces under consistent cutting conditions. A section of pork ribs was chosen as a representative test specimen.

Torque, force, blade speed and sample data were collected from fifty tests. No relationship was found between blade speed and cutting force, optimum blade speed range was found to be defined by cut quality. There was an approximately linear increase of cut force with feed speed. Monitoring of cut progress by off-line analysis of cutting force using a signal processing technique and by comparison with a characteristic force-plot was shown to be feasible. Future work will continue to define optimum blade speed and feed-speed - cut-force relationships for other cut cases, real-time cut monitoring will be developed.

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