MEASUREMENT AND SIMULATION TOOLS TO ASSIST WITH THE AUTOMATION OF CARCASS DISASSEMBLY

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Background

Over recent years there has been a trend worldwide towards increased further processing of red meat carcasses to create new value-added products. For example, in the early seventies over 90% of New Zealand export lamb was in whole carcass form. Twenty years later, just over half of all lamb exported from New Zealand was further processed into lamb cuts and boneless product, and eight years after that, in 1998, over three-quarters of exported lamb was further processed (New Zealand Meat Producers Board, 1971, 1991; Meat New Zealand, 1998).

Lamb and beef processing, as with most other industries, also has a continual drive for increased efficiency and optimisation of returns. This drive has been two-pronged in its approach: on the one hand, a wider range of further-processed, table-ready cuts complete with novel packaging is being developed; on the other, there is a desire for more efficient processing through automation. As a result, a conflict has arisen between increased processing complexity and the desire for further automation. The increasing number and complexity of cut specifications has caused processing operations to become more complex. Consequently there is a demand for techniques that can evaluate the full impacts of automation concepts, individually and as part of an overall processing environment, in a cost-effective way, prior to investing time and effort transforming the concepts into tangible equipment.

In the design and development of automation for carcass disassembly, several mature simulation and software tools exist that can give a detailed static and/or dynamic analysis of the machinery (and the materials and components used in its construction) before a single piece is fabricated. Programs such as SolidWorks (www.solidworks.com) and Algor (www.algor.com) use the latest in finite element analysis and three-dimensional representation techniques to provide detailed information on the viability and performance of different designs, rapidly accelerating the design and development process and reducing the risk involved in new concept development.

Although these tools provide valuable insights into equipment design and development, they are not intended to deal with the other major source of variation – that of the raw material being processed. As a natural product, lamb and beef carcasses are inherently variable, making automated processing difficult, yet automation is critical for reducing processing costs, improving product quality, and developing new value-added products.

Furthermore, because many different cut specifications and cutting patterns are processed during a single operational shift, the complexity of the carcass disassembly process is greatly increased: automation, labour utilisation and even space are reconfigured on multiple occasions within shifts. The ability to assess the combined impacts of automation, labour and processing layout collectively will greatly increase the ability of processing companies to respond to the wide-ranging requirements of customers while maintaining a cost-effective operation.

In this paper, the author will discuss some of the research and development efforts that have been undertaken at AgResearch (formerly MIRINZ), on its own and in conjunction with its research partners, that address the requirements of both raw material and process for simulation, measurement and optimisation.

Three-dimensional Carcass Modeling

The push for increased processing efficiency and novel products requires a greater understanding of the anatomical structure of the lamb carcass, including the underlying properties of its various components and the way in which the components interrelate. Rapid developments in computing and computer graphics technology have enabled virtual reality to be applied to meat processing and cutting (Lay *et al.*, 1997). AgResearch targeted this technology as a means of representing and interactively visualising the anatomical structure of carcasses. The development of a virtual reality model that describes the anatomical relationships shared by individuals within a species, will enable carcass attributes to be accurately inferred from a small number of targeted measurements without the need to explicitly measure the entire carcass.

To date we have developed a full computer model of the 'virtual lamb carcass'. This model comprises full parametric descriptions of the three-dimensional surface of each major muscle and skeletal component as well as the outer surface. The carcass model provides an excellent visualisation tool for understanding the anatomy of the carcass. Details of this model can be found elsewhere (Crocombe *et al*, 1999; Anon., 1999a, b; Bell *et al.*, 2000a, b). Figure 1 shows a two-dimensional image of the three-dimensional generic carcass model. As well as describing the three-dimensional structure of each component, the model also incorporates a framework that describes the skeletal connection points of the major muscles, along with the articulation of major skeletal joints. This ensures that anatomical validity is retained under various transformations of the model. It also will enable the effects of joint articulation on disassembly as well as on meat quality to be assessed.

Figure 2 illustrates the model in slightly more detail, by showing just the leg with the outer surface (a), the underlying muscle structure (b) and the muscle structure exploded (c). This explosion illustrates the 'virtual dissection' that is possible using this technology, and opens up significant opportunities in other areas such as education and butcher training. The three-dimensional user-interaction possible within this type of modelling environment is a significant advance on existing computer-based anatomical and myological references currently available (Aus-Meat, 1998, Jones and Burson, 2000). Additional information can also be included in the model, allowing this information to be viewed within the context of the carcass anatomy. For example, muscle parameters such as collagen concentration or normal ultimate pH could be displayed to facilitate new product development. The model could also be used to simulate the chilling process or the stresses and strains various parts of the ovine anatomy undergo during and after slaughter, which has a significant impact on muscle quality.

In the context of automating the carcass disassembly process, the carcass model has wide-ranging application. The 'generic' carcass model can be customised to represent individual carcasses using data from one or more of a variety of measurement technologies. This customisation allows the components of each carcass to be characterised, providing information for making better grading decisions or for controlling automated disassembly processes. The results of such customisation are illustrated in Figure 3. The three lamb carcasses are all shown at the same scale, and have identical weights and fat contents (as measured by fat depth at the GR site) – hence they are of the same grade (using conventional grading systems). However, they are of widely differing shape, and if disassembled into conventional meat products by cutting on anatomical landmarks, would yield meat cuts of similar weight but significantly different shape. This variation causes problems for companies wanting to produce table-ready, high-quality food items, because significant shape variation can detract from quality as perceived by the consumer.

The ability to customise the model to a particular carcass is shown in Figure 4. Since the model is parametric, this customisation is almost instantaneous and requires orders of magnitude less information from direct measurement than is contained within the model representation. At this point the implications become significant, since the measurement data required to customise the model accurately can focus on areas of significant variation, because anatomical reference data are already implicitly contained within the model. Measurement data can be obtained using a variety of technologies and can be evaluated collectively, with the necessary level of accuracy determined by the end-product specifications. The same model can even be used to optimise carcass selection and/or breakdown based on specific end-product specifications, with the customised model providing the specific cutting patterns for each carcass regardless of whether processing is implemented manually or automatically.

The carcass model has been converted into a finite element model suitable for computer-based CAD applications, such as automation and machinery design. This allows machinery to be assessed using the entire range of carcass size and shape variations that occur over a full season prior to instigating any costly machinery fabrication and evaluation.

Advanced Measurement Technologies

Although the carcass model provides an interpretation framework, it will only be as accurate as the measurement information provided to it. Many non-contact measurement technologies have been investigated over the years, including ultrasound (Lui and Stouffer, 1995; Goldenberg *et al.*, 1996) and video imaging systems such as VIASCAN (Ferguson *et al*, 1995) and CVS (Tong, 1997). Others have incorporated a model-based approach to interpreting real-world measurements (Trevelyan, 1992).

Our research has focused on two measurement techniques to provide the necessary real-world measurements for model customisation: three-dimensional surface profile measurement and dual-energy X-ray absorptiometry (DXA). Three-dimensional surface profile measurement has been used to obtain surface shape information in a manner similar to that implemented as part of the Danish beef carcass classification system (Madsen *et al.*, 1996). Figure 5 illustrates a lamb carcass surface profile generated using off-the-shelf 3-D scanning technology. From this 3-D surface profile, three-dimensional measurements at predetermined anatomical locations can be extracted and used as surface constraints during model customisation. The resulting customised model can then be used to provide cutting locations that correspond to anatomical data, to ensure more accurate cutting. Given that muscle connection points are defined within the model, inferring skeletal location from surface data also provides valuable information for developing more advanced disassembly automation. In particular, current investigations into boning along muscle boundaries will require detailed information as to the location of these boundaries that, while difficult to measure, can be inferred with a reasonable level of accuracy from a customised carcass model.

We have also done 3-D measurement work on beef. Computer models of the three-dimensional surface of beef sides have been developed to provide the basis for automating the process of trimming hot fat (Loeffen and Clarke, 2000). The ability to trim fat from hot carcasses has significant advantages in terms of ease of trimming as well as the resulting end-use and value of hot- versus cold-trimmed fat. Currently the results of this work are proprietary to Meat & Livestock Australia (MLA).

While skeletal data for automatic carcass disassembly can be inferred from external surface data, it is more difficult to infer muscle size from surface information alone. Dual-energy X-ray absorptiometry (DXA) technology offers significant promise in providing the necessary information on skeletal location as well as soft tissue composition. Figure 6 shows a screen-shot of a lamb side that was scanned using a medical DXA scanner. Human body analysis software incorporated in the medical DXA scanner (Hologic QDR 4500A X-ray Bone Densitometer, Hologic, Inc., Waltham, Massachusetts, USA) was used to estimate the composition of 24 lamb sides (Clarke *et al*, 1999). Using the segmentation feature in this software, estimates were generated for the whole side as well as the leg region only. These estimates were then compared with equivalent dissection results, and also with chemical analyses of the sides. The DXA results and actual composition are very highly correlated (Table 1). DXA offers significant promise not only as a method of determining accurate anatomically based cut locations, but also as a method by which carcass disassembly can be performed to produce accurately sized and weight-ranged table-ready cuts. Interpreting DXA measurements within a customisable carcass model will enable the development of more cost-effective implementations of this technology, and work in this area is already under way at AgResearch.

Automation of the carcass disassembly process offers benefits in labour savings combined with improvements in product consistency, hygiene and yield. However, there are also significant benefits to be made in automating the numerous product handling and transfer operations between each subsequent disassembly or cutting operation. Given the increasing complexity of cutting patterns and product specifications, the ability to control the flow of individual cuts through the disassembly process necessitates the measurement and identification of each cut at least once during the disassembly process. Similarly, the ability to manipulate product automatically requires that the product size, shape and orientation be determined or controlled prior to handling.

To achieve this, three-dimensional surface measurement has been implemented to identify and measure the shape of meat cuts prior to automatic handling and processing. Figure 7 illustrates the 3-D surface profile of a barrel lamb forequarter. Based on this surface information, the cut can be identified and its size, position and orientation determined. Examples of how this information might be used are shown in Figures 8, 9 and 10. Figure 8 shows the pickup location for a robotic suction-based gripper as calculated automatically by computer from the 3-D surface information. Figures 9 and 10 show the three-dimensional image capture hardware and robotic manipulator in operation loading lamb loins into a loin-boning machine. The robotic manipulator uses a custom suction-based gripper device, developed at AgResearch (MIRINZ), to grip the lamb loins at a location calculated by computer from the measured 3-D information. It is anticipated that future installations will use custom mechanical manipulators that will be significantly lower cost than the general-purpose food-grade robot pictured here.

Simulating the Impact of Automation

Given the increasing demand for meat processors to manufacture high-value, table-ready food products, the need for smart automation is tempered by the need to configure processing lines for maximum productivity. Often the cost-effectiveness of new technology and automation is hindered by the constraints of existing processing line configurations combined with the extensive cost of testing physical equipment. To address these issues, a project is underway to develop a software simulation package that will enable operations personnel to objectively assess the impact of automation, alternative process layouts, and different cuts' specifications on productivity and efficiency.

A screen capture of the current beta version of the simulation is shown in Figure 11. The main window contains a graphical representation of the product flow within a typical boning room. Each processing or transfer operation is represented iconically by one of three or four generic objects. Each of these objects contains a discrete, real-time simulation engine that can be configured to mimic a real-world process. When the simulation is run, the combined effect of each object (operation) dictates overall throughput, with graphical indications of utilisation presented on-screen to indicate potential bottlenecks. Adjusting each of the object's parameters to accurately represent manual, semiautomatic or automatic operation allows the impacts of automation to be interpreted in the context of processing line efficiency and production. Cut specification schedules can be created to mimic real-world production schedules, and a wide range of statistical information is collated at a carcass, cut and batch level for further analysis and comparison.

Targeted specifically at the food processing industry, the simulation tool will allow solutions to food processing needs to be designed quickly, with minimal investment in capital equipment and full evaluation of design before construction and implementation, and also allowing a full review of existing designs. This will save time and money, reduce risk and provide a powerful graphical representation for enhanced communication and clarity.

Conclusion

The key to efficient processing of natural product is the ability to characterise each item before processing, combined with the ability to collectively implement automation, and utilise manpower and space in a manner that ensures flexibility with maximum productivity. The modern automated construction systems that build our cars, washing machines and other household appliances are highly flexible and dynamically configurable, but deal with components that are essentially identical, having minimal natural variation. These systems are also generally targeted at assembly, rather than disassembly processes.

This paper has presented three linked approaches to the issue of more integrated and automated carcass disassembly. These include the use of anatomically accurate models that, combined with intelligent measurement systems, provide a way of dealing with the significant natural variation of animal raw materials. The use of model-based measurement systems allows measurements to focus on the variation among individual carcasses and cuts. Finally, the simulation of the processing environment, optimised according to individual productivity, capital and output requirements, allows the development of automation that is targeted in its approach and near optimal in its implementation.

Acknowledgements

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MIRINZ was fully integrated with AgResearch as of 1 October 1999.

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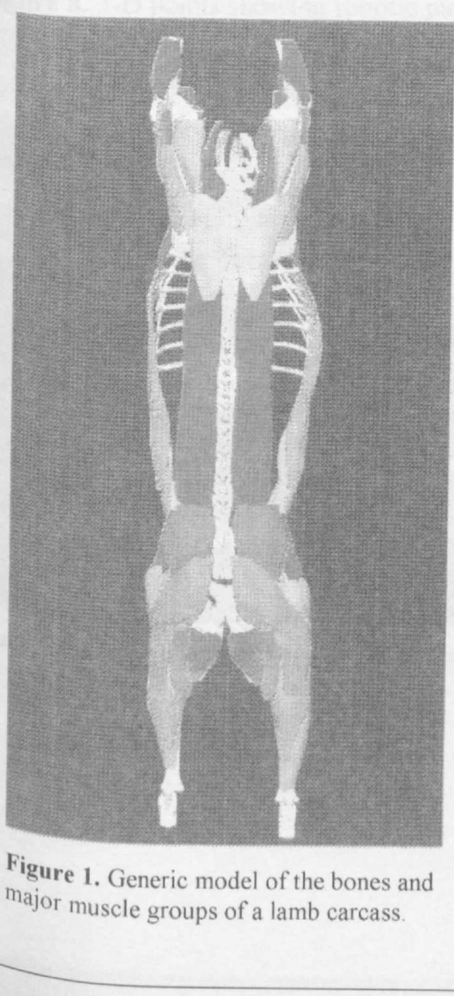

Figure 1. Generic model of the bones and major muscle groups of a lamb carcass.

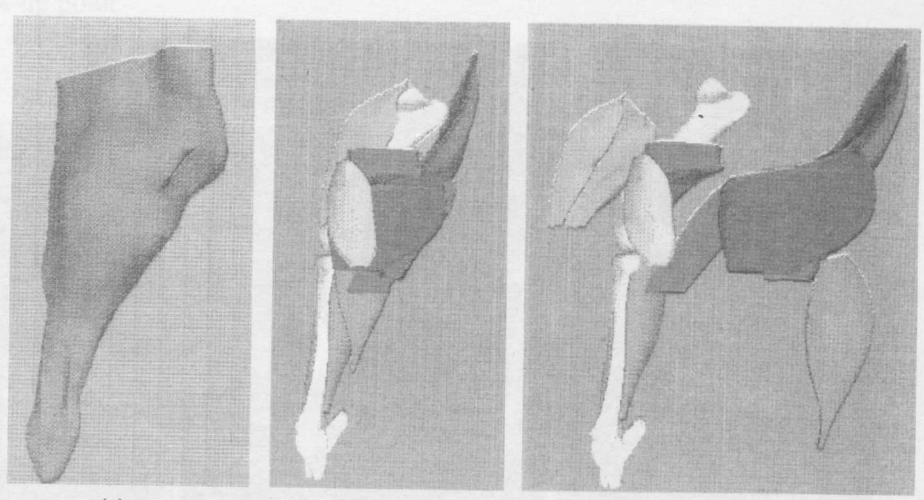

Figure 2. Generic model of a lamb leg showing the outer surface (a), underlying muscle and skeletal structure (b) and an exploded to illustrate the 3-D interrelationships (c).

TABLE 1: Relationship between DXA measurements and dissection results of lamb legs.

	r^2	rsd	DXA prediction equation	Mean
DXA Mass	0.99	92 g	1.02 * leg mass – 63.14	4292 g
DXA Lean	0.96	115 g	1.21 * leg lean + 55.45	2714 g
DXA Fat	0.93	66 g	0.87 * leg fat – 49.16	966 g

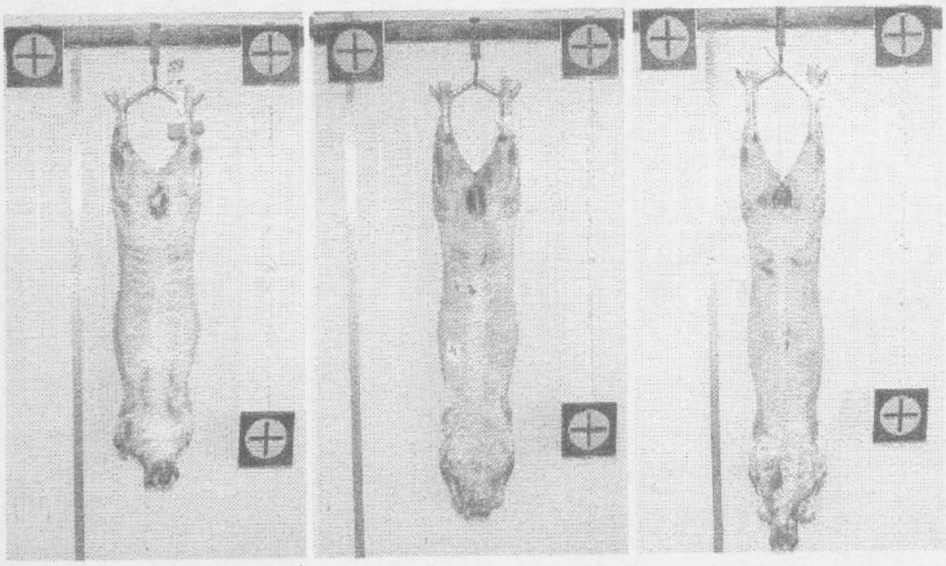

Figure 3. Lamb carcasses of the same weight and fat depth and varying shape.

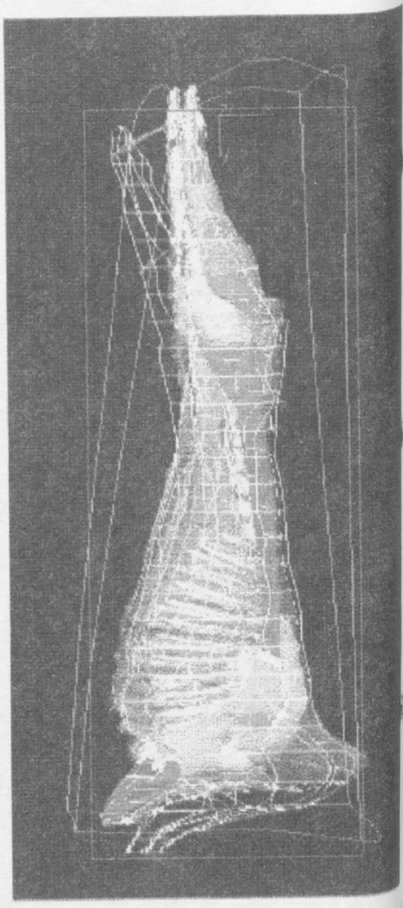

Figure 4. Customised carcass model
three different carcasses.

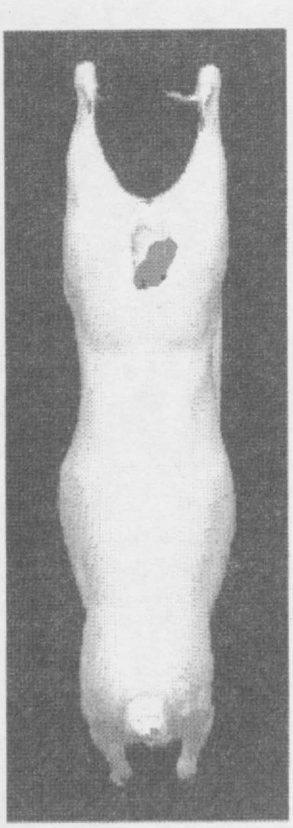

Figure 5. 3-d scan of a lamb carcass (smoothed).

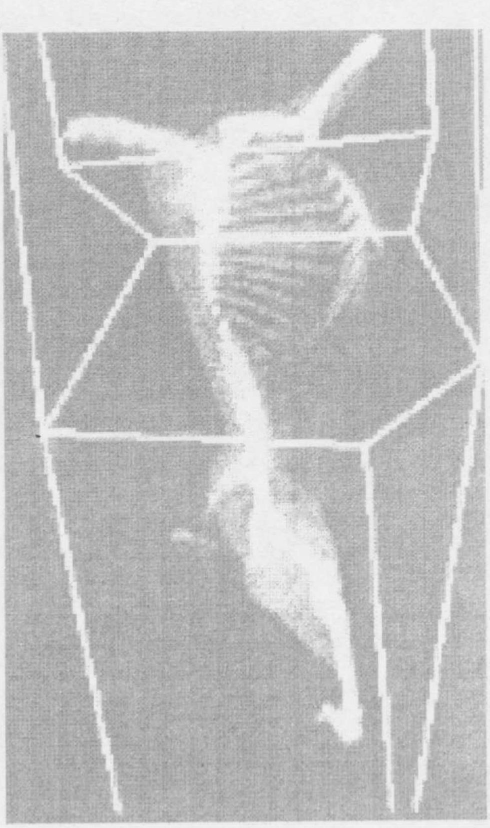

Figure 6. DXA scan of a lamb side.

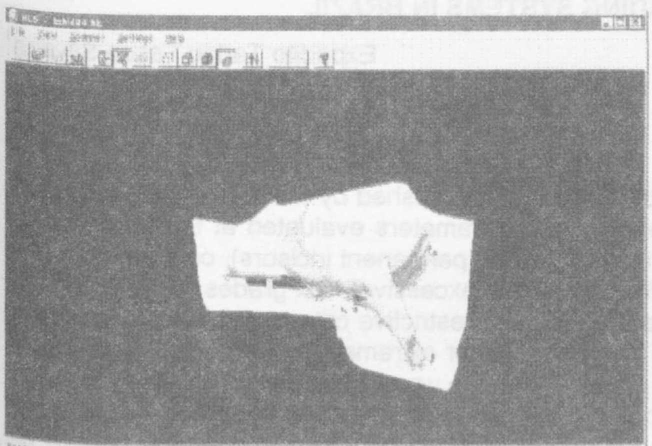

Figure 7. 3-D scan of a barrel lamb forequarter.

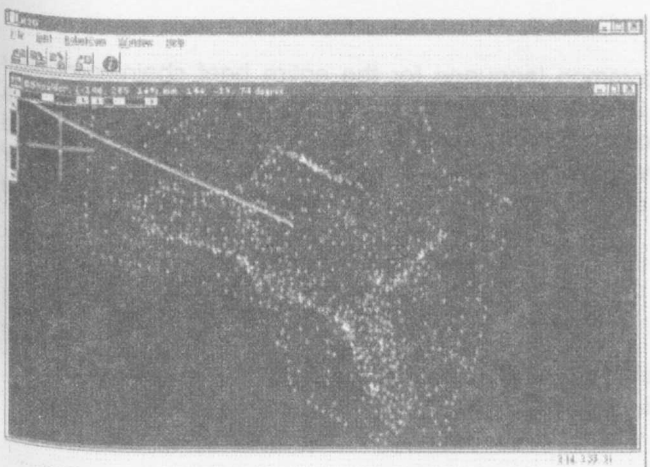

Figure 8. 3-D points showing robotic pick-up point.

Figure 9. 3-D scanning system for lamb loin identification.

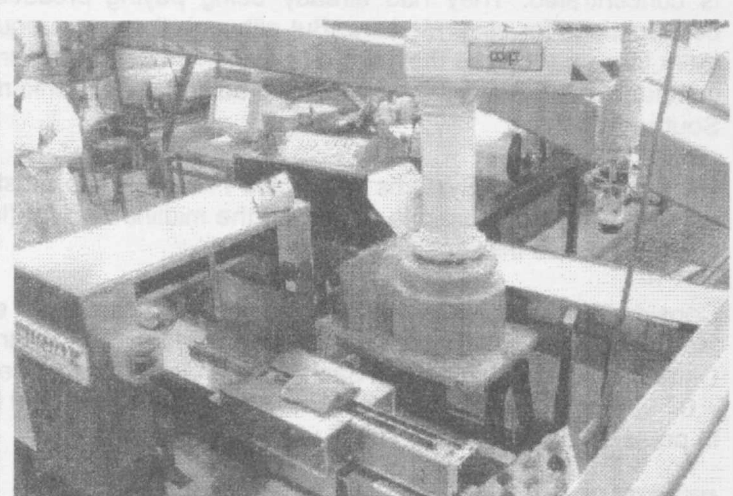

Figure 10. Robotic loading of a MIRINZ loin boning machine.