SENSORY GUIDED ROBOTS FOR CUTTING AND HANDLING OF MEAT PRODUCTS

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INTRODUCTION

Advances in information technology have given rise to expert systems for applications in medical diagnosis, material selection and many others. The existing architecture of an expert system includes an information or a knowledge base, and with the use of predefined rules, it is possible to examine different data in order to reach a decision. The correct decision relies on the formulation of the correct rules. Existing systems tend to assume that an expert is available for consultation and they are too often used to assist an expert rather than act as an intelligent unit, replacing certain functions of the expert. Intelligent robots must operate automatically, making decisions based on sensory data, and have the ability to update their knowledge from previous action. A robot should be able to deal with uncertain situations by applying rules that allow it to find exact data for a decision, or using fuzzy rules to arrive at a possible solution. This paper presents the potentials for sensory guided robots in cutting and handling of meat products.

The Challenge of the food industry

The food industry has many complex manufacturing and processing automation problems to which existing robot technology cannot easily be applied. Food processing operations usually involve handling of complex shaped, non-rigid, sticky or slippery products. In tasks such as packaging, the manipulation of the product is often required. The automation of such tasks would be beyond the capabilities of current robot technology. Intelligent robots guided with vision and other sensors are therefore envisaged in order to overcome the unpredictable nature of the food environment.

Conditions in the food industry also present other problems uncommon to those in engineering manufacture. Hygiene, contamination and 'cleanability' are key issues when robotic devices are used with food products.

Collaborative research between the University of Bristol and the Institute of Food Research-Bristol (IFRB) has shown that the application of robotics technology in the food industry can be made possible with the use of artificial vision and intelligence.

The Opportunity for business

The high cost of recruiting and increasing shortage of staff in this labour intensive sector, together with the often unpleasant, repetitious and hazardous working environment make the application of robotics and automated systems extremely desirable. In the United Kingdom four million beef animals are slaughtered each year. With an average dead weight value of £500 per animal this realises a potential gross beef turnover of £2.0 billion. A reduction in processing costs of only a few per cent would result in a potential saving of millions of pounds per year in UK alone. World wide turn over in beef animals exceeds £90 billion, strengthening the case for business opportunities. A broader indication of this is reflected by the volume of world meat production:-

Year	1985 (million tons)	1988 (million tons)
Bovine meat	47.9	48.3
Sheep & goatmeat	8.3	8.6
Pig meat	59.3	61.5
Poultry meat	31.5	36.3
Other meat	3.7	3.8
TOTAL	150.7	158.5

(Source: Poultry International July 1988)

It is clear that the potential for robotics and automation is high and that savings, if achieved with the use of such technologies, will create a tremendous business opportunity for food producers. The obvious question must therefore be: why has this opportunity been ignored?

TECHNICAL REQUIREMENTS

Many of the operations in meat production and processing involve handling and positioning of irregular, non-identical pieces of meat or food items. These range in size and weight from whole beef carcass sides 3m high and weighing up to 200kg, to chicken portions of a few hundred grams or sliced products a few millimetres thick. As yet robotics and automation systems have not advanced sufficiently for tasks involving such a range of food products to be automated. Furthermore, the majority of robotics systems, currently in use within the manufacturing industry, do not meet the exacting requirements of food production systems.

It is necessary to investigate and identify 'universal' characteristics of new handling devices, such as gripping devices and mechanical hands for food products. Such handling devices, once defined and developed, will broaden the range of applications of existing robots and will advance this technology by extending the design of such devices to meet the needs of food production systems. Sensors ranging from vision systems, tactile or touch sensors will need to be defined and used to increase the capability of handling devices. These capabilities must allow handling of slippery, pliable, sticky, soft or wet products without any noticeable damage to food surfaces. Other requirements include being resistant to microbiological contamination, non-tainting and self-cleaning (or easy to clean). A robotic system used in handling and processing meat or food products must be self cleaning self maintaining, intelligent and guided by advanced sensors, such as computer vision, and capable of being fully integrated into production systems of today and the future. Extensive literature surveys of work in the USA, Europe and Australasia have shown that little research is being done to produce systems suitable for use in the meat/food industry. Previous work has been confined to application of existing teach and play-back industrial robots rather than generating new technologies utilising intelligent, sensor-guided systems.

SENSORS AND ARTIFICIAL INTELLIGENCE

The existing programming architecture of industrial robot and computer vision systems follow that of the traditional computer based technologies. Changing the task or the robot path, requires a change to the programme. If the architecture of a robot system were to
match that of an expert system, then reprogramming would be possible by the construction of rules that re-define the robot action using new data. This requi[res] 'flexible' robot tooling, fixtures and ha[ndling] that can cope with a large variety of items [in] an industrial application. The limitation[s of] such items and indeed the physi[cal] restrictions imposed by the robot itself (su[ch] as robot reach) would constitute part of [the] knowledge. The main characteristics of [an] intelligent robot system, particularly for [use] in the food industry, should include:

a) The system must oper[ate] automatically, making decisions with the [use] of sensory data, and have the ability [to] search for alternative solutions in case [of] difficulty.

b) Data gathered using sensors, [and] knowledge is updated by learning fr[om] previous action,

c) An intelligent robot system should [be] able to deal with uncertain situations [by] applying definite rules that allow it to fi[nd] exact data for a decision, or using fu[zzy] rules (based on probabilities) to arrive at [a] possible solution.

One example of current research, namely [the] robotic meat cutting research, is present[ed] here to illustrate the above.

ROBOTIC MEAT CUTTING

Industrial meat cutting is a difficult [and] unpleasant occupation. It is highly labo[ur] intensive, requires a skilled labour force [and] is expensive. The basic carcass struct[ure] within animal types is similar, altho[ugh] individual bone positions will vary accordi[ng] to the degree of fat cover, weight [and] carcass dimensions. Amongst the ma[ny] types of sensors, computer vision is one [of] the few that can provide the surface det[ail] for an automatic meat cutting operati[on]. By using 3D models of typical carcass[es] held in a data bank, several 2D images m[ay] be used in conjunction with data mappi[ng] techniques to generate geometric models [of] the carcass for robot guidance. Cutti[ng] strategies as part of an expert system w[ill] define the cutting path of the robot, whi[le] sensors in cutting devices will allow 're[al] time' course changes to avoid unforese[en] obstructions, such as broken or displa[ced] bones. To meet the production speeds [of] the food industry a vision system will [be] required to operate at high-speeds [in] varying light conditions.

Under an Agricultural and Food Resea[rch]

Grant for a Link project the cutting of forequarter beef is being investigated. Initially the work involves the cutting of meat from the forequarter into unspecified shapes or sizes, but leaving little meat behind on the bones.

After a thorough examination of the methods used by butchers in cutting meat from a forequarter beef, it was noted that handling of the meat in the same way as the butcher will be beyond the capabilities of robots for many years to come. Many of the operations involve grasping and manipulation of large, irregular and floppy or non-rigid pieces of meat. Definition and implementation of a robotic system that performs the task of meat cutting in the same way as a butcher is considered to be a long term objective. The initial step, however, has been to choose a research direction that leads to the realisation of sensory guided robots to perform the task of meat cutting following a technique more appropriate to the robot rather than people.

SYSTEM REQUIREMENTS

Fig. 1 shows a schematic of the various elements of the system to be implemented. The main subsystems required are:

a) A powered cutting device attached to the robot arm. This is a reciprocating powered knife specially designed for the task.

b) A robot with sufficient reach and degrees of freedom needed to manipulate the cutter whilst delivering the necessary drive power to produce the cuts needed.

c) A force sensor providing feedback to the robot controller. This is needed to guide the knife parallel to bones whilst touching and separating meat from it without cutting into the bone.

d) A vision system that uses input from a number of cameras to define the carcass features required for cutting.

e) A system control computer for deciding the start point, the end point and the rough path of each cut. This is the decision processor which takes the form of an expert system.

f) A database of previously measured carcasses for which the cutting data in (e) is available.

It is intended that the proposed robot system will cut the forequarter beef by moving its reciprocating powered knife through meat, with the cutting blades following a particular bone profile, defined by the cutting scheme of Fig.2, separating meat from bone at the interface. The determination of the path for each of the required cuts is to be done by the use of the vision system and a database of cutting information for carcasses measured and cut previously (see Fig.1).

Assuming that the features to be measured by the vision system will result in the definition of the co-ordinates of a number of reference points on the carcass describing its geometry, then R_{jk} can be defined as a matrix of (x_j, y_j, z_j) representing the x, y and z co-ordinates of each of the chosen reference points j on carcass k. R_{jk} contains physical measurements of the carcass k in the vision frame of reference. k being the carcass index taking the values 1 to N(T) where N(T) is the total number of carcasses at time T for which R_j has been measured and kept in the database. This database is also to contain the start point, the end point and the rough path for each of the cuts required for the meat cutting operation on carcass k. For a given cut i on carcass k, the start point of each cut is denoted by a_{ik}, the end point by $á_{ik}$ and the rough path by D_{ik}. a_{ik} and $á_{ik}$ are point vectors in the robot frame and D_{ik} a path function joining a_{ik} to $á_{ik}$. It is important to note that the cutter is expected to follow D_{ik} as the path for each cut i. However, because the bone positions vary it is expected that with the use of force feedback the robot will guide the cutter along a different path closer to the bone. This new path is denoted by d_{ik} for $k = c$ where c is the carcass to be cut. Since d_{ik} is closer to the bone being followed in cut i, a higher yield may be achieved highlighting the importance of force feedback.

The Robotic meat cutting task

By performing a number of manual cutting trials using a selection of forequarter beef carcasses, a general cutting scheme for de-boning has been defined. The scheme is shown in Fig.2 and this has been shown to be a more appropriate de-boning scheme for the robot system envisaged. The schemes are also defined in such a way that eliminates handling of cut meat. The database information is essentially defined using this cutting scheme and the work on the expert system is intended to use this data to define the cutting information for the robot. It is envisaged that the operation of the robot system will take the following form (see Fig.1).

1) Take and process images of the forequarter held by the handling unit and define R_{jc} where c is the index of the carcass to be cut.

2) Compare R_{jc} against R_{jk} for k = 1 to N(T) held in the data base to find a match. If a match is found against a given carcass m, then use a_{jc}, $á_{jc}$ and D_{ic} for the matched carcass i.e. for c = m. If a match is not found use a_{is}, $á_{is}$ and D_{is} where s denotes a standard predefined set of points and paths for each cut defined by the cutting schemes and adjusted to compensate for size and shape variations of the carcass.

3) Use a_i and $á_i$ in the sequence defined by the cutting scheme to guide the powered knife (Fig.3) attached to the robot along the path D_i whilst using the force feedback to make any necessary adjustments to the path.

4) As each cut is performed, record the actual path followed d_i and compare this to D_i. If significant deviations are noted then take error recovery measures or raise an alarm, otherwise complete the cut.

5) At the end of each cut, add the values for R_{jc}, a_{ic}, $á_{ic}$ and d_{ic} to the database, as new data and update N(T).

RESULTS AND PROGRESS TO DATE

Research so far has lead to the following:

a) Definition of an algorithm for controlling the path of a powered knife moved by a robot along an unknown bone profile, using force control to adjust the trajectory of the cut. Fig.4 illustrates the schematics of the results from a trial cut using the robot to cut a forequarter rib section.

b) Definition of cutting schemes and first approximation of the standa measurement data and information, R_{js}, a_{is}, $á_{is}$ and D_{is}.

c) Implementation of a system for tri using a standard industrial robot.

d) Carcass measurement for a numbe forequarter beef carcasses leading the definition of R_{jk}, a_{jk}, initially.

e) Implementation of software for vision system for performing measurements.

It is important to note that the architect of this system (Fig.1) compares with shown in Fig.5 which is a general syst architecture for an intelligent robot.

FUTURE WORK

Current research is intended to continue investigate forequarter beef cutti Extensions of this work are envisaged include the cutting of primals and portions for beef as well as lamb, port other such carcasses using robotics. Th however, involves further research into handling as well as cutting of a variety meat portions. To date little is underst about the handling characteristics of products to help the development of robo systems. This is the subject of anot Bristol University project in Autom handling of non-rigid products.

In the forequarter beef cutting proj however, more specific work will be purs in the following areas:

i) Investigation of force sensing characterise the influence of carc and meat variations.

ii) The use of vision to define R_{jc} for given carcass and definition tra vision-robot co-ordinate formation rules.

iii) Study of a larger selection of b carcasses to determine the variati in R_j, a_i, $á_i$ and D_i.

iv) Investigations of methods using fu relational inferences to define a_{ic}, and D_{ic} from R_{jc} and the cutt data provided in the database.

v) Experimental implementation of a full system to demonstrate forequarter beef cutting and to further investigate the process of updating of the database, or knowledge base learning.

CONCLUSION

This paper has presented the general requirements for applying sensory guided robots to cutting and handling of meat products. Force sensing and vision have been identified and used as the main type of sensors. Some early results of work in the area of forequarter beef cutting has been presented and a general notation is used to describe the process of robotic meat cutting and to define the problem systematically. So far the research has lead to the successful cutting of meat from a forequarter rib section using force feedback only. This has involved the full implementation of a cutting device and force sensing devices used with a standard six axis robot.

Other past and current food automation related research at Bristol University include packaging of poultry, slicing and processing fish and more generally the handling of non-rigid products. The systems produced so far all involve the use of computer vision and force sensing. Other than the usual labour savings and improved work conditions for skilled workers, significant savings could also be made due to the consistency and accuracy of vision and robotic systems. Future research should aim to improve the techniques and to explore practical methods to cope with the food environment and the production speeds imposed. Consideration of other applications in whole-meal assembly, cooking, packaging and processing of food products is also becoming essential in view of shortages of staff and difficulties in maintaining and improving quality as well as hygiene standards. Despite recent short term initiatives by U.K. research funding bodies to support selected research programmes, there is considerable need for a more substantial and co-ordinated research strategy in this field, backed up by adequate resources possibly at an international level.

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ACKNOWLEDGEMENTS

The author wishes to thank the following organisations and people.

- UK Agricultural and Food Research Council (AFRC) for funding of the Robotic Meat Cutting Link Research Project at Bristol.
- IBM (UK), SKF Automation, Sun Valley and Automatix UK for their support.
- Dr Peter Brett, Mr Colin Bailey, Mr Neil Maddock, Mr Graham Purnell, Mr Mark Swain, Mr Steve James and Mr Paul Newman for their support and contribution to Food Robotics Research at Bristol University.
- The AFRC Institute of Food Research, Bristol Laboratories for provision of material for testing and access to food processing facilities.
- Last but not least Mrs Joan Powell for typing this publication.

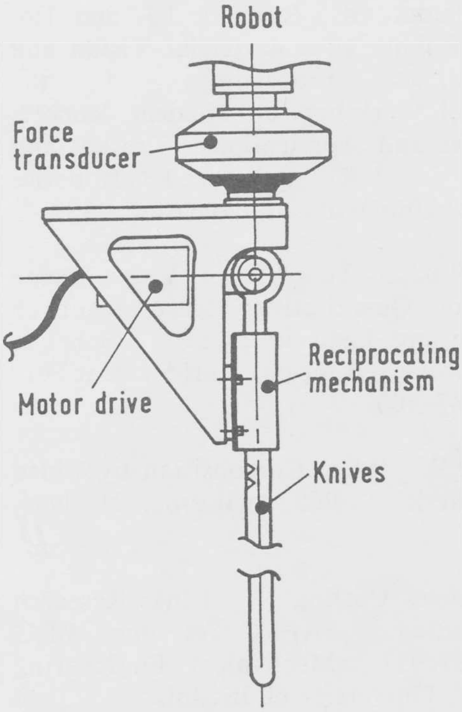

FIG.3 CUTTING DEVICE AND FORCE TRANSDUCER

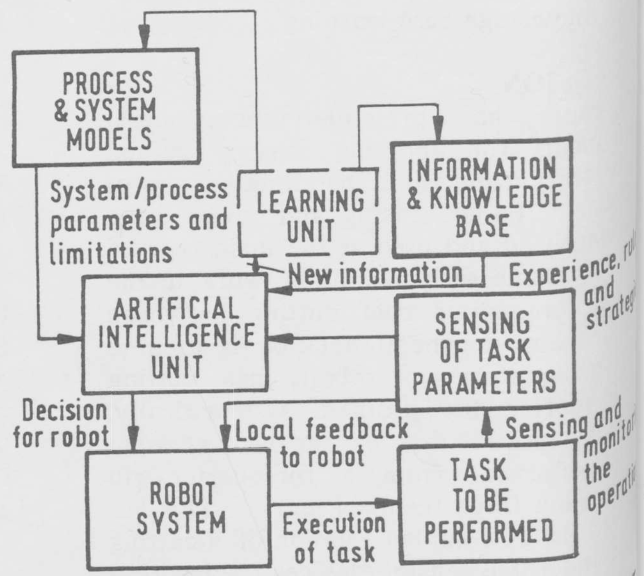

FIG.5 ARCHITECTURE OF AN INTELLIGENT ROBOT SYSTEM

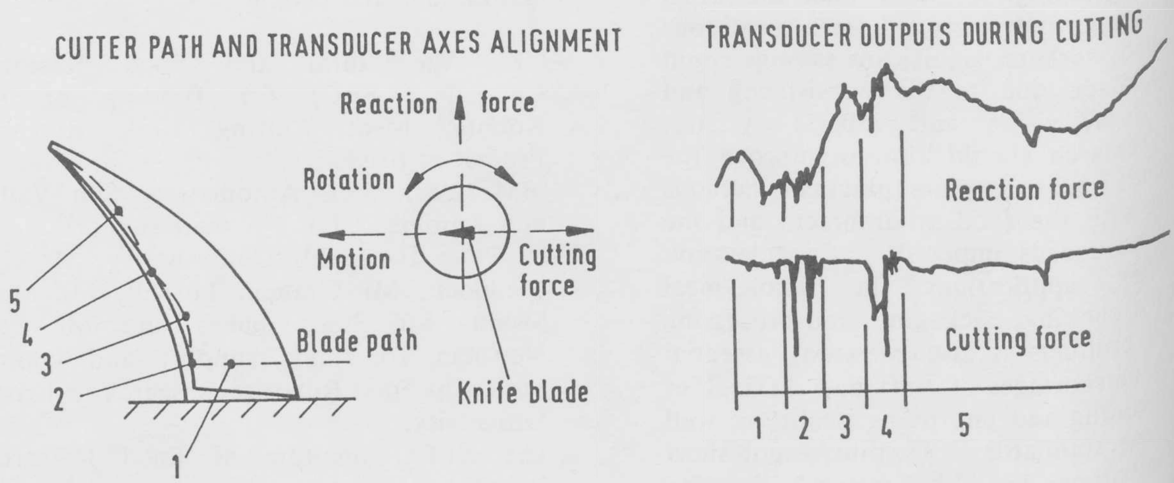

FIG.4 RESULTS FROM CUTTING OF A BEEF FOREQUARTER RIB SECTION

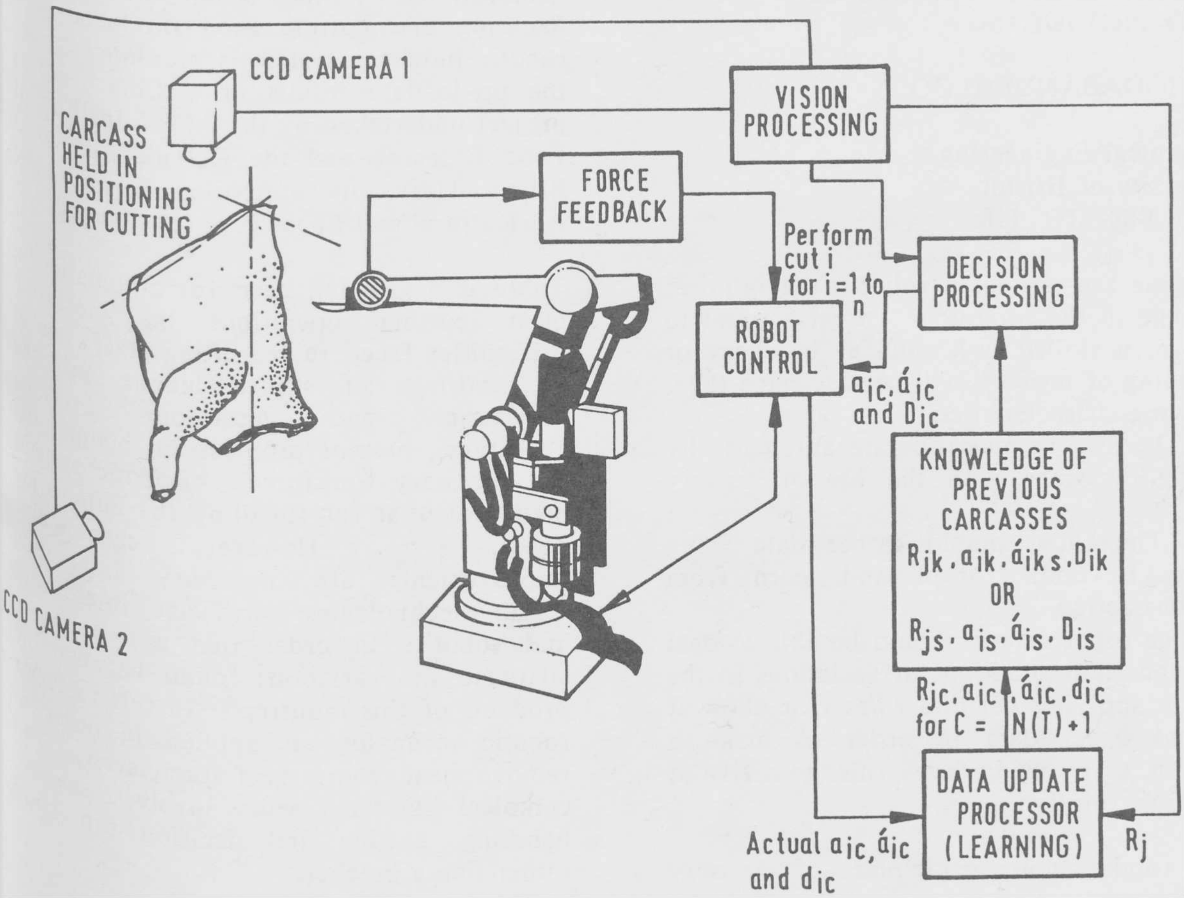

FIG.1 ROBOTIC MEAT CUTTING SYSTEM GENERAL CONFIGURATION AND NOTATION

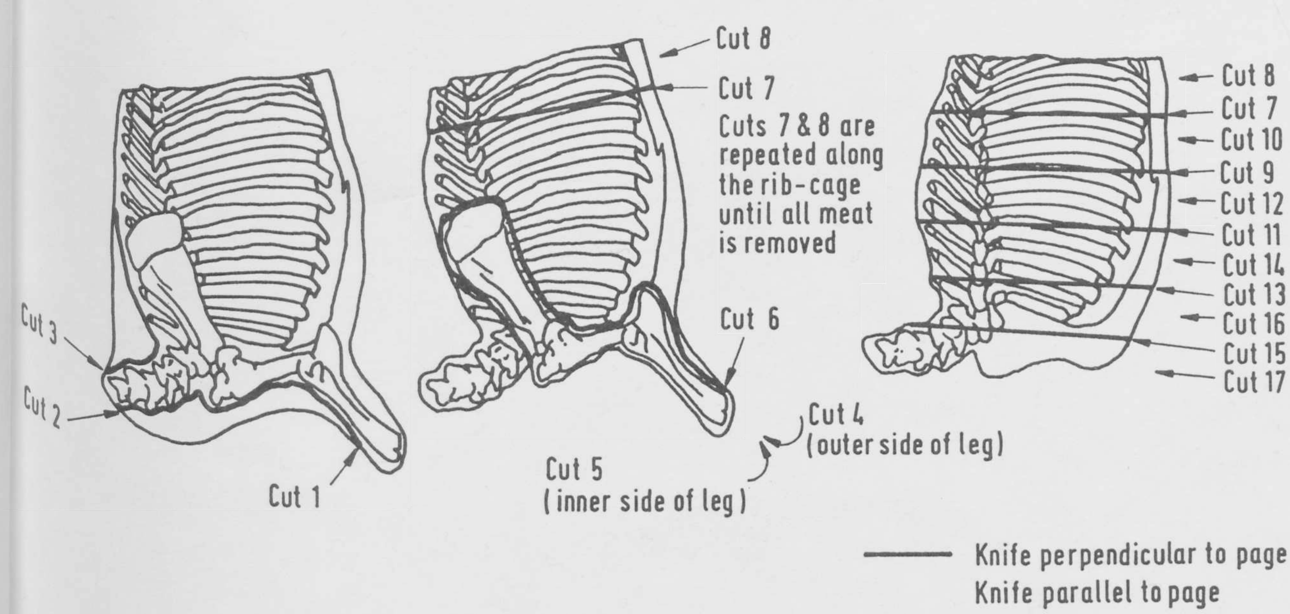

FIG.2 STANDARD CUTTING SCHEMES FOR i = 1 to n WHERE n = 17

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Changing the task of a robot often requires a change to the program. To get a robot to perform a skilled task such as butchery or packaging of meat, it will need to have the following characteristics:

a) The system must operate automatically making decisions with the use of sensory data.

b) The robot should gather data using sensors to update itself and learn from previous action.

c) The robot system should be able to deal with uncertain situations or variations in the task by applying definite rules that allow it to find exact data in order to make a decision, or by using fuzzy rules to arrive at a possible solution,

The fundamental principles of sensory guided intelligent robots can be demonstrated by robot systems to be used i handling and cutting food products. robotic butchery system is presented, giving the up-to-date results of a Link research project undertaken by the AFRC Institute of Food Research and the Robotics Group a Bristol University supported by the U Agricultural and Food Research Council.

There is a growing need for automation i meat cutting operations as increasing difficulties faced in recruiting staff, due t the shortage of skilled labour and th unpleasant and hazardous working conditions, present problems in maintaining the necessary workforce. Robotic systems offer potential for fulfilling the automation needs. However, considerable improvements are necessary integrating sensor technologies, artificial intelligence and robotics in order that a system ca adapt to the variations found between th products of this industry. In this research robotic technology is applied in order t remove meat from a beef forequarter. Th complete system will involve sensing handling, cutting and decision processing rather like a butcher.