RESEARCH TOWARDS THE USE OF ROBOTICS IN MEAT PROCESSES

by

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SUMMARY

Increased consumer concern on hygiene issues, difficulties in recruitment, seasonal variations in demand and increasing high labour costs, in the face of fierce competition have heightened the need to provide an automation solution.

Intelligent Robotic Systems offer the potential versatility required. However, there is still the need to improve and integrate enabling technologies such as sensors, grippers, robotics and expert systems. Laboratory demonstration systems devised towards meeting the needs in cutting and meat packaging operation are under current research. The solutions investigated are discussed together with further developments in robotic technology to be used to enhance the capability of the systems studied.

INTRODUCTION

The potential for the use of robotics and automation in the food sector may be presented in terms of population of labour involved in production, currently estimated to be 2,500,000 people in the EEC, and the value of products consumed each year, currently 240,000,000,000 ECU's in Europe and £30,000,000,000 in the U.K. alone. Cost reduction and improved quality in a sector that has to cope with short product life cycles and the increase in demand, with fluctuations on an almost daily basis, provides significant opportunities for the automation industry to supply systems to food manufacturers.

Difficulties in automating tasks in the preparation of meat products arise due to the non uniform nature of products. Meat off the bone is particularly non rigid and variations in the physical and mechanical properties of each piece can be large. Such is the case in many cutting and handling operations ranging from tasks carried out in slaughter to tasks in packaging and in the preparation of ready meals. Off the shelf automation solutions already exist to some tasks. Usually this requires machinery used to present the processing system with uniform working conditions. However such machinery is often applied to products of small variations in size and shape and is not cost effective when applied to short batch manufacture. In these situations and in complex manipulation duties it is necessary to employ human operators. Human operators use skill to meet the aims of the task dealing with each product piece on an individual basis and also provide for quality control. However difficulties in maintaining a skilled workforce and intense market competition have increased the search for versatile automation solutions.

Intelligent Robot Systems

Present day robots are commonly found operating with the aid of sensory devices that enable adaptation to a changing work environment including variations in the components being handled. In some cases artificial intelligence has been used in the form of an expert system with real-time links with electromechanical systems to control robots. Marchant (1) illustrates applications in agricultural sectors and Khodabandehloo and Rennell (2) describe a robotic system that is devised to play a game of snooker.

Advances in sensory systems such as vision have enabled industrial robots to perform more flexible and complex tasks. The full potential of the industrial robot is still not being exploited fully because of the inability of current system architecture to deal with the uncertain and undefined situations. The existing programming architecture of industrial robotic systems and computer vision systems is based on the traditional languages where situations of uncertainty cannot be easily programmed or understood. Operator intervention normally takes place to provide the solution, which involves further programming or indeed conditioning of the environment to a simple and predictable form. An appropriate way ahead may be to provide the system with the knowledge and decision-making ability of the operator by the use of an expert system. Expert systems are gradually being introduced into many applications including medical diagnosis, system control and others.

A typical architecture for an expert robot system is shown in Figure 1. The expert system interprets the task description and controls the robot by reacting appropriately to the behaviour of the product by the use of behavioural models, previously stored. Behavioural models reflect experience in the human system. The behaviour of the product is detected using sensors such as vision and force/displacement measurements at the gripper of the robot. In handling meat products the system will need to react to variations in the product such as shape, size and compliance, and surface properties such as texture, sticky and wet conditions.

At the University of Bristol research is being directed towards systems with such capabilities.

METHODS AND DISCUSSION OF SKILLED ROBOT SYSTEMS DEVISED TOWARDS THE PROCESSING MEAT PRODUCTS

Robotic systems capable of handling and cutting meat and others for deboning have been under investigation for many years. Two specific examples are presented here.

Robotic Meat Cutting

An expert robot system is being constructed with the capability of deboning forequarter beef carcases. Industrial meat cutting is a highly labour-intensive, skilled task and in general an unpleasant occupation.

Figure 2 illustrates the various elements of the system to be implemented. The principal subsystems 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 carcases for which the cutting data in (e) is available.

Laboratory trials with knives as the cutting device have shown that powered reciprocating devices to be suitable for robotic cutting.

Cutting strategies as part of an expert system will define the cutting path of the robot. The basic carcass structure within animal types is similar, although individual bone positions will vary according to the degree of fat cover, weight and carcass dimensions. Amongst the many types of sensors, computer vision is one of the few that can provide the surface details for an automatic meat cutting operation.

Geometric models of typical carcases used with a number of 2D images from strategically positioned CCD cameras will enable the generation of cutting strategies to separate meat from bone by driving the cutting device through meat with the cutting blades following a particular bone profile. The profile is followed and knife speed and deviations in bone position are accommodated by maintaining appropriate force levels detected on the knife. A set of the types of cuts necessary to debone the carcass can be stored in terms of the typical geometry of cuts and of the motion required. The position of cuts to be scaled parametically will be referenced to identified anatomical points. To date schemes for deboning meat from an unknown bone profile have shown successful application of the profile following scheme which employs force feedback. Studies continue on undertaking cutting characteristics that will lead to the discrimination of tissues. In addition a carcass database is being compiled to provide information for the automated location of cutting trajectories.

The current research on this project is supported by the U.K Agriculture and Food Research Council. Another project involving meat removal is being carried out by Clarke, Key and Tang in Australia (3). The Australian project is the most similar to the work at Bristol where a reciprocating cutter is driven along the meat bone interface under force and movement control. The test piece used is the foreleg of beef. Success in the project will lead to the cutting of larger sections.

Automated Poultry Packaging

Visits to several poultry packaging plants in the U.K. revealed that over 30% of the workforce are involved with handling the product and that a good deal of this occurs during packaging. Packaging of poultry portions can involve simply putting thighs or quarters into a bag until the correct weight is achieved whereupon the bag is sealed. Alternatively, a more complex task would involve the arrangement of portions neatly in a tray for presentation to the customer prior to sealing and pricing. The latter case involves manipulation of a poultry portion on or off the bone from an unknown position, orientation into a known location within a packet. The task often requires some turning and straightening of the portion as well as translation from one location to another.

In order to assess the needs of an automated robotic system the scheme illustrated in Figure 3 was constructed. This consisted of a robot and gripper, robot controller a vision system and a central computer for control of the cell. With the task defined, the control sequence of the cell begins with recognition and location of a poultry piece from a 2D image using the CCD camera and vision system. The recognition process also determines orientation of the product. The orientation is random as this is most likely to be the case on a conveyor. In the laboratory a stationary flat surface is used. Based on the size and orientation of the product, the orientation and size of the grasp by the gripper of the robot can be determined. The handling part of the process is carried out and the sequence is terminated on placing the product piece in a presentation tray for retail.

Product Recognition

Recognition is achieved by a model matching technique. Three techniques are most often used.

1. Boundary model
2. Template model
3. Features model

The first technique has been applied by Schwartz and Shasir (4) and has been used to locate partially obscured objects such as poultry portions overlapping on a conveyor belt, however the technique assumes a small deviation between the boundary of the unknown object and the boundary model. The template method uses a comprehensive model taking into consideration texture as well as shape and size. However a large memory is needed to store each model and manipulation of such large sets of data is computationally time consuming.

The Feature model is the scheme employed by the system considered as it is relatively simple to implement and uses a comparatively small memory size. Feature models are stored by the system, based on object features such as area, length and width. The unknown object is then recognised as the same type of object as the model with which it most closely matches. As described by Khodabandehloo (5), the size of each feature is assumed to have a normal distribution across samples and a close match is indicated by a small standard deviation. It is difficult however to employ such a scheme to identify overlapping samples. In the application considered here the process of product recognition proved to work well. It was also found that bruised products could be detected using a monochrome vision system (5).

Fixed Weight Fixed Price Packaging

Packaging of meat products into sealed trays is widespread. Often a number of portions are placed into each tray. A detailed evaluation of the market in the UK revealed an immediate application for the robot system described above in the packaging of meat portions in poultry. Fixed-Weight-fixed-price packaging is a recent product area requiring considerable judgement of the operator. Based on size the operator will hazard a guess as to which portions should be packaged together to achieve a minimum weight. The closer to the minimum weight the greater the profit margin. However by attempting to reduce deviation from the minimum value the more likely a package will be rejected by failing to achieve the minimum weight. Reworking adds to the cost. An automated system could locate, measure and record the weight and position of each portion leaving a robot to pick out the appropriate portions. This it would have the potential to accomplish with a low margin of error.

Gripper Design

The design of the gripper for handling meat portions is an important area of study in devising a system. The requirements for poultry portions include:-

Able to handle non-rigid products without damage
Able to deal with slippery surface conditions
Hygienic and easily cleaned
Handle objects up to 1.0 Kg
Pick up moving objects
Handle different portions
Operate at high speed
Light weight
Inexpensive so that it can be replaced regularly
Rugged and reliable
Deliver portion with final orientation
Easily attached or detached
Capable of accommodating a variety of touch sensors

Grippers currently available for industrial use do not meet the above requirements and a prototype gripper has been developed for use in the poultry packaging demonstration cell. A selection of designs have been considered.

A pneumatic muscle finger arrangement developed at Bristol could be adapted with further work. Finger motion is based on varying compliance around the air cavity of a compliant finger material. This construction offers suitability for a food environment as it is easy to clean and disposable units are a possibility. The finger inherently provides force control in an open loop sense and can adapt to the profile of an object as illustrated in Figure 4.

The angled jaw type gripper shown in Figure 5 was also found to be suitable. A jaw angle of around 30 degrees gave satisfactory results when handling portions of chicken breast. Too large an angle produced a scissoring action whereas with too small an angle the gripping force between the jaws to achieve lifting is unacceptably high. The above experimental system performed consistently and was reliable for the picking and placing of chicken breast and chicken drumsticks. However the system has not been extended to cover other requirements that are performed by human operators such as manipulation and decisions regarding placement of portions to maximise customer appeal. Greater manipulation capabilities will require more dextrous grippers and possibly a change in robot configuration.

Robot Configuration

A programme of research to propose and evaluate multi-arm robot design configurations is in progress at the University and is a fundamental study in the field of robotics. The application of such machines will not be as limited as single arms to product size and shape and will relax the complexity of gripper design requirements. Multi-arm robots will be capable of manipulation without the need for other fixtures or jigs. For example a two arm robot would enhance the capabilities of the poultry handling system and the versatility of the butchery system by enabling manipulation of part of the product. With two arms (bi-arm) the ability to straighten and twist a portion off the bone into a required shape will be achieved more simply.

Currently a bi-arm robot is under construction for laboratory trials. The design is planar as shown in Figure 6 as this will enable positional performance criteria to be assessed more readily against simulated results which have already provided considerable background to the present stage of the work. The simulation package, developed for multi-arm robots at the University, has enabled studies on the kinematics and dynamic characteristics of various configurations and has assisted in the procurement of onboard functions such as collision avoidance of the arms and product and in control algorithms to ensure that motion of the links are time coordinated with the product moving along a particular trajectory. There is also a requirement to ensure that there is little deviation in the relative position of the grippers when transporting a product. A possible strategy to be investigated in laboratory trials is for one gripper to lead based upon the required trajectory of the product, the second gripper maintaining the required relative motion. As variations in relative position will lead to force transmission through the product by virtue of product stiffness, the accuracy to which a relative displacement between the grippers is to be maintained is a function of the force levels that can be tolerated by the product.

It is anticipated that systems of the types described above will be introduced over the next decade.

CONCLUSIONS

This paper has examined requirements for intelligent and robotic systems and system elements for cutting and handling automation in the meat processing industry. The concept of 'intelligence' in Robotics is introduced as the use of expert systems for real-time control of electromechanical systems. The specific tasks of butchery and packaging of food products have been presented as examples of intelligent tasks for Robotics Systems. It is necessary to state that there is a fundamental system architecture that constitutes the basis for 'advanced' robots for skilled tasks. Although the examples presented tend to be specific, the wider implications for the automation of other tasks is evident.

The two example applications described above in butchery and packaging indicate the basis by which systems could be implemented. Laboratory studies have shown the difficulties in adapting to the wide variation between products and this has lead to some solutions and has highlighted needs for further investigation. In particular, attention is drawn towards alternative end effector designs and alternative manipulator configurations. Indeed the prospect of multi-arm robot systems, will lead to greater system versatility and hence wider scope for robot applications.

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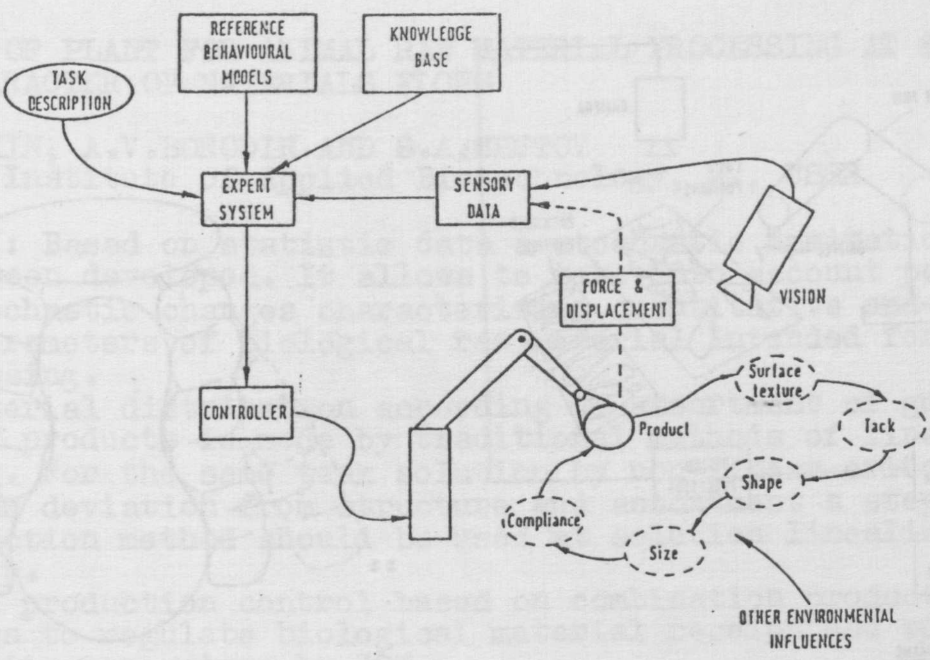


FIG 1 *ARCHITECTURE OF AN EXPERT ROBOT SYSTEM*

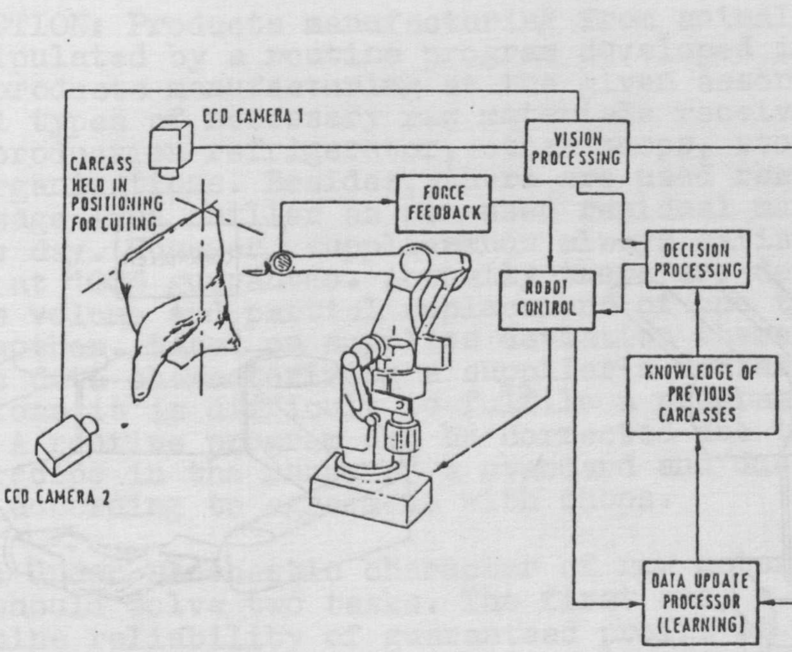
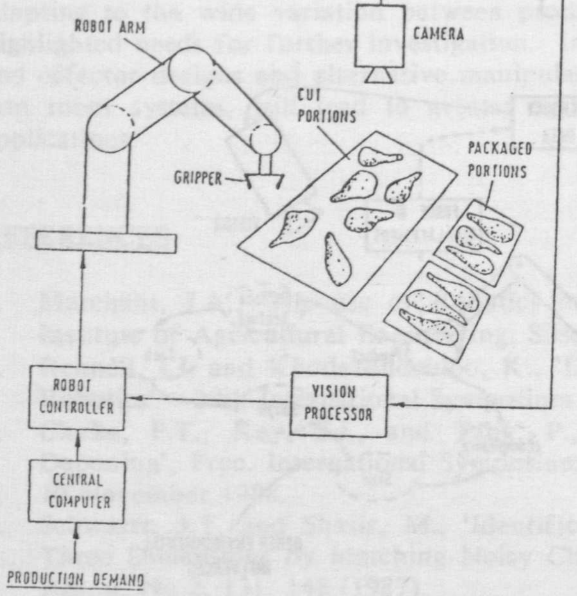
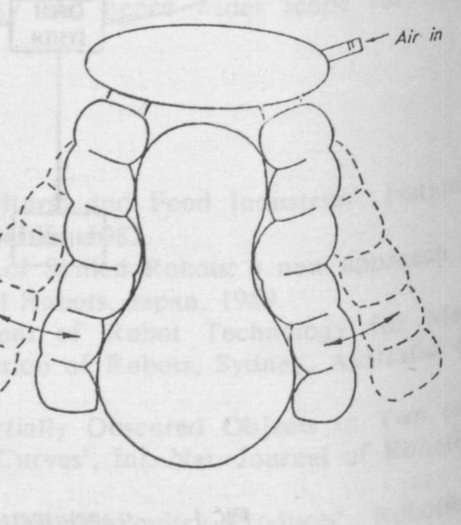


FIG 2 *ROBOTIC MEAT CUTTING SYSTEM SCHEMATIC*



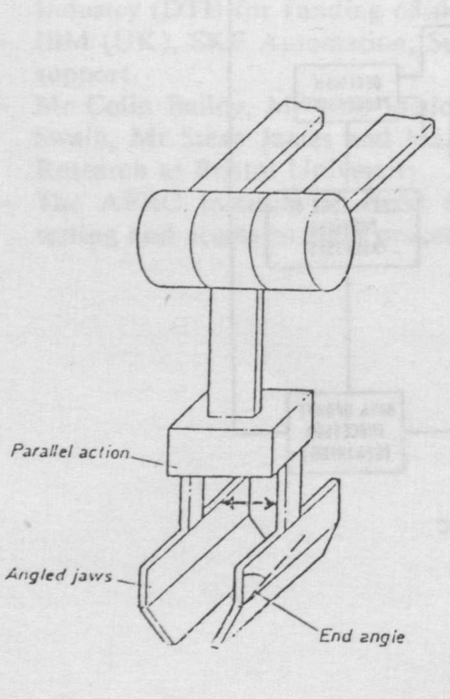
SCHEMATIC OF THE PROPOSED CELL FOR POULTRY PACKAGING

FIG3



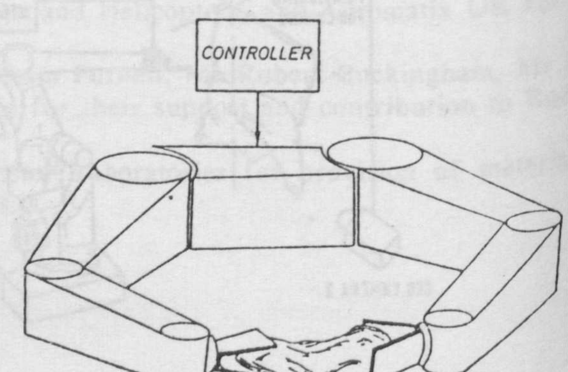
PNEUMATICALLY OPERATED FINGERS

FIG4



ANGLED JAW GRIPPER

FIG5



BI -ARM ROBOT SYSTEM

FIG 6