Feature Article

Achieving robotic meat cutting

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Implications

- Automation solutions for cutting meat are presented, integrating sensor technologies with robotics performing skilled butchery.
- Achievements include robotic cutting with examples for beef, pork, lamb, and poultry.
- Adopting pathways have been based on economic benefits using cost engineered solutions for sustainable total-life operation.
- Achieved improvements in safety, work environment, hygiene, and quality have been demonstrated in commercial applications.
- The human factors, "ownership", and management of change have been highlighted.

Key words: butchery skills, business-drivers, change-management, robotic butchery

Introduction

The meat industry continues to have significant need for automation in the primary stages of slaughtering, breakup (butchery of whole carcasses into primal pieces), and general handling and cutting using robotics. If robots were to be accepted, at the very least, their performance needs to match the capacities of skilled operators or butchers. The efforts to achieve robotization in the meat sector have met with exceptional challenges over the past 4 decades and many initiatives remain the subject for Research and Development (R&D) since the late 1980s (Khodabandehloo, 1989). Commercial breakthroughs have been reached and are in use; however, the widespread adoption requires changes in management approach as well as simplified technological breakthroughs that deliver cost advantage and sustainable use at low running costs. Barriers to adoption include space restrictions and access to technical skills to operate automation. Motivation at senior management for engagement and sustained commitment to automation is needed.

There are many applications that will become practical in the coming decade, but a significant number will need to see radical changes in meat industry approach to overcome the barriers and tackle the management of change as well as cultural acceptance towards adoption of robotics and automation. Technology suppliers' supporting role, and direct facilitation assisting host plants, will be essential if maturity in commercial solutions is to be reached. Management of change for a host user needs to deal with both the plant and human resource transition, including motivations and attitudes at all levels of workforce and management. The engagement of the entire supply chain is also key, including retailers and the end consumers of the products as food. The commitment at board and top management is equally as important as the ownership of those responsible, impacting the transitions throughout the life of a given installation: from conception, to first operation, to steady state and daily use, periodic upgrades; and eventually, final decommissioning at the end of the equipment life.

This article will focus on robotic meat cutting, based on personal experiences and developments, with examples of the projects instigated and achieved by the author over the past four decades.

Skills in Meat Cutting

People working in meat plants have developed the core natural skills of recognition by vision and touch sensing. Human dexterity in grasping and manipulation is essential to the most basic of butchery tasks (Khodabandehloo, 1989). Figure 1 illustrates the worker capabilities that are often taken for granted, requiring significantly greater Research and Development (R&D) within the fields of Robotics and Artificial Intelligence if the advancements are to make much greater impacts, delivering more applicable automation for widespread meat cutting tasks, presently performed by people. Motivating factors to apply automation (Figure 1 right) have remained strong over the past decades and the meat industry is only too aware of them.

"Skilled" robots, though the subject for research since the early 1980s, have emulated the skills in manual butchery.

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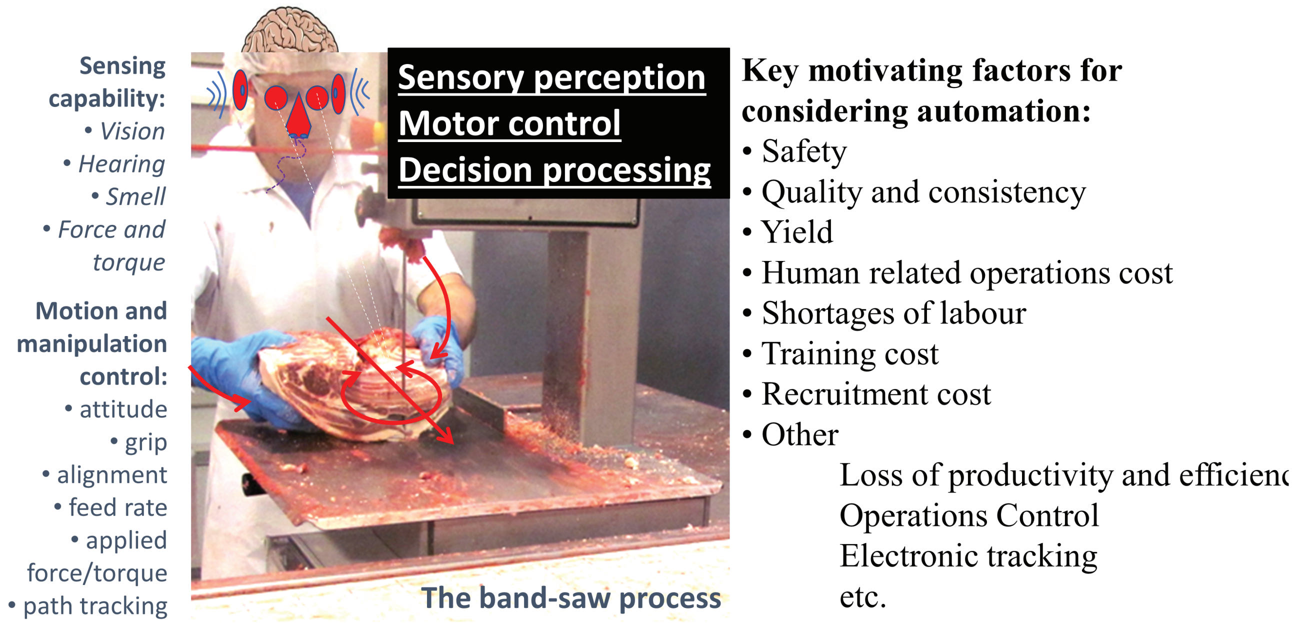

Figure 1. Skills competences and robotics – motivations for automation.

Developments have tackled the engineering of the solutions covering meat sensing and handling, applying the automation and equipment as well as software capabilities offered by the methods and the technologies of the time, each decade, until the present day (Khodabandehloo, 1993).

A skilled persons performing meat cutting have natural sensing and perception capabilities that have been developed from childhood to the time when they possess the understanding of carcass anatomy, meat behavior, and dexterity in both meat and tool handling to perform the tasks of butchery.

A person applies the ability to see and determine how to hold and manipulate meat, which has diversity in characteristics, shape, size, color, and physical variability. Hand-eye coordination with dynamic control and adaptation in motion in a real-time situation is naturally achieved by human workers. Many of the decision processing and "motor" control steps performed by butchers are subconsciously executed, whilst using "neurocognitive" capabilities as well as geometric and behavior "models" of meat.

Consider a band-saw operation used to perform separation of meat in highly demanding jobs (Figure 1). The task involves tracking and control of meat movement or the piece (in this case a lamb shoulder) whilst applying motion to achieve separation along a specific path. The same process applies when handling of a knife or a powered tool to achieve separation, breaking up a carcass, or trimming a primal piece. The following outlines specific methodology and approaches applied to meat cutting to achieve robotization.

Butchery Skills and Automation

The first step to engineer a robotic solution in the tasks of meat cutting requires the realization of a handling process that presents the meat for robotic cutting. Three approaches have been applied:

(1) to handle the meat by a robot and use cutting tools or devices to perform separation along the desired cut paths, Figure 2a;
(2) to have a robot carry the tool, with a handling and holding solution that presents the meat to the robot in a known position and orientation, Figure 2b, with the carcass fixed and static; and
(3) the carcass on a moving conveyor belt or hanging on a hook or a gambrel whilst resting on an upright moving belt positioned at an angle to the vertical (Figure 2c).

It is important to consider cost engineering the final solution from the outset, ensuring both practicalities and the simplicities in the design of each element and provisions for a "total life operation". Aspects of cleaning or washdown as well as maintenance must be inherent. Making the solution ergonomically sound with straightforward operator interfaces is essential for the sustainable use of the final equipment. There is no point in designing an automation cell in concept, which then needs years of additional development to provide for its robustness or acceptance in a meat processing environment. The following includes specific considerations that influence definition of robotics for meat industry users who may be prepared to invest:

1) The physical presentation of the meat from a previous manual operation to the starting point of automation needs to be clearly established as this part of the line is usually safeguarded for robotic cutting. In particular, this consideration needs to have simple fixation and handling, engineered to allow determination or sensing of anatomical features of the meat, facilitating geometric referencing in the 3D space relative to the work coordinate frame of the robot. Controlled

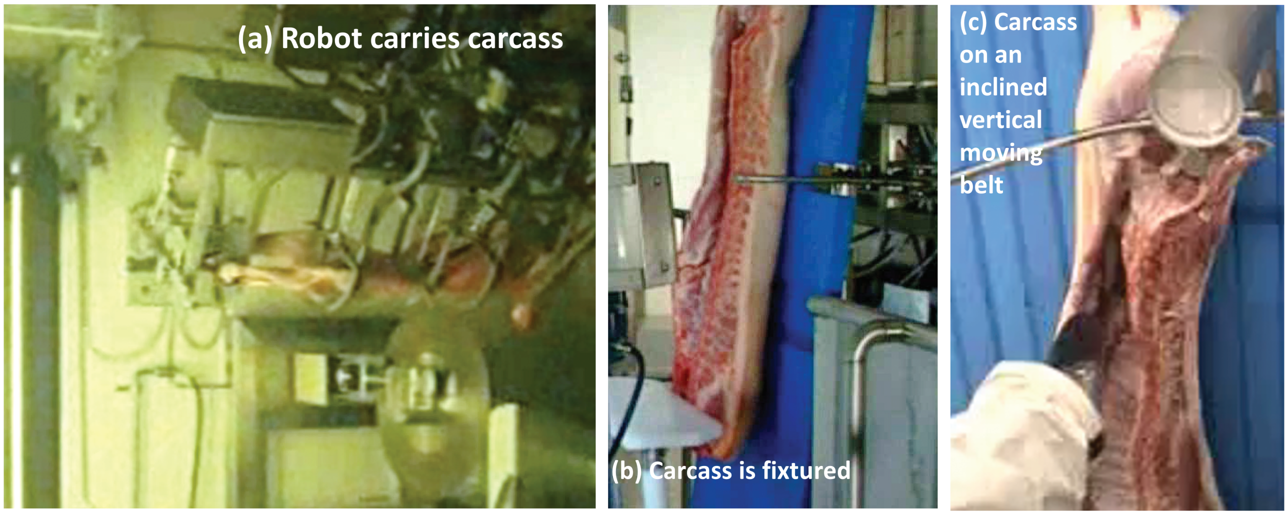

Figure 2. Handling options for robotic carcass cutting.

presentation and handling of the meat avoids costly sensing solution to allow position and movement of the meat to be tracked in real-time alongside cut path generation, needed for the robotic cutting actions that achieve separation.

2) Once meat positioning and fixation have been achieved, the mechanisms for restraining the meat piece or the carcass during cutting need to be designed into the fixation or handling solution. In many, if not all, robotic cutting applications, movement of the meat during cutting results in cut path deviations that have an undesirable impact on the cutting line positions.
3) Determination of cut trajectories using anatomical features with affordable sensing technologies. An advancing enhancement of the process capability is the application of X-ray, Infrared (IR), Ultrasonics, and other sensing solutions that take robotics beyond human capability.
4) Cutter technologies in their diverse variety may be and have been used with robots for meat cutting. Use of water jets, ultrasonic knives, powered cutters, or shaped knives all have their respective applicability. It is worth noting that laser beams burn the meat, and like water jets, are useful as single dimension cutters. Separation in 2D is achieved by the robot moving the laser beam or the jet of water. Water jets have successfully been applied in trimming, whilst knife-blades, common for manual butchery, may be robotically manipulated to follow separation along complex cut trajectories. The side of the knife in contact with meat may be used to manipulate or restrain the meat whilst the sharp edge is performing separation along the path of the cut. This is useful in meat cutting as achieved by skilled butchers, especially when removing meat from a complex shape bone. Adapted power tools with blades are used in many automation applications as they reduce the need for a robot to mimic the same hand actions of a butcher moving a knife back and forth to achieve separation by the sharp edge.
5) Meat pieces being separated need to be controlled with a handling solution that provides for transfer of cut pieces. Restraining of the cut pieces and the original primal during separation is important to avoid changes in the cut trajectory. This is essential if the anatomical positioning of the cut is critical in the separation steps. For example, when cutting a hanging carcass, separation needs to start with the lower positioned primal cuts, whilst maintaining fixation of the carcass and the separated meat primal pieces, before, during and after cutting, to ensure primal cut positions higher up the carcass are unaffected by gravity.

The achievements of the past 40 years have delivered robotic cutting, several practically adopted with appropriate investment and considerations in the management of change within meat plants. The following are specific examples involving carcass scribing (bone deep cutting – for example across the rib bones along the cut lines that separates the belly and the back primal pieces without cutting through the meat), and full primal separation for pork, lamb, poultry, and beef production (Khodabandehloo, 1992).

Breakup and Butchery of Carcasses

After slaughtering, carcass breakup is to achieve anatomical separation of main primal pieces. This is often performed by people using hand-held powered tools or bandsaws. The use of robotics achieving the same outcome, duplicating the skill capabilities has been achieved and operational in existing plants. The systems use imaging (computer vision or X-ray) to determine cut paths that a robot, carrying a tool, can follow to perform the cuts. The motivations to use such technology include increased efficiency and savings in labor, yield optimization as well as improved work conditions.

In several examples, computer imaging is a low-cost option that provides the data for cut path calculation (Figure 3), including start and end points and the trajectory for the robot to follow for each cut. The sensory information is adjusted for each carcass side ensuring conformity in the anatomical separation,

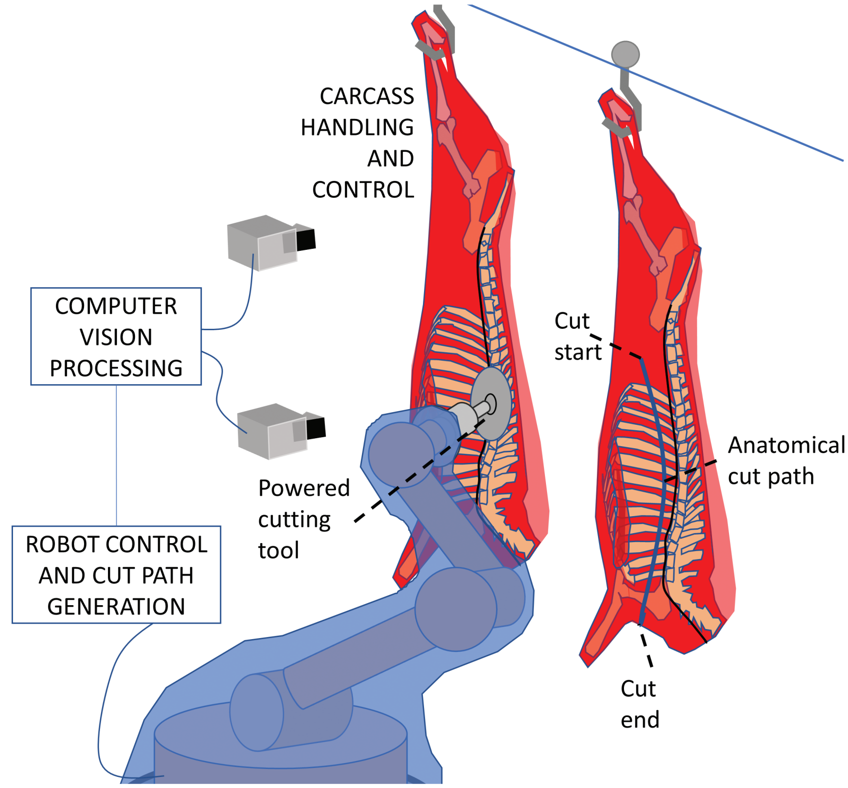

Figure 3. Concept of a skilled robot cell for cutting.

with permissible user defined path adjustments that optimizes yield in higher value products. Force sensing may be added to allow abnormal conditions to be detected as well as determination of cutter tool changes over time such as sharpness. The capability to position each cut "intelligently" using digital information; and more accurately and consistently than the manual process, allows optimization of the separation of primal pieces automatically allowing for size and shape variability, in a manner that gives higher yield on the more valued primal pieces.

In the examples that follow the concept of Figure 3 has been validated with gains in yield complementing efficiencies reported from meat plant over the past 2 decades.

Pork

In 1970s and 1980s, robotics in United Kingdom and Europe was primarily targeting the car and conventional manufacturing sectors. Researchers were occupied with assembly of engines and various appliances or solutions related to welding or aerospace application including deburring and polishing. Food and meat industry applications, whilst at their infancy, focused on specific industry motivated projects (BRITE/EURAM, 1988). Figure 4 presents the outcomes in the form of two solutions:

- the first using a fixation solution to perform 4 cuts, without cutting through the whole cross section of a pork carcass side. Separating of bones and main muscle tissues left the primal cuts attached to the "back fat". The middle cut was performed first as a vertical anatomical cut separating the belly and the back, including the cuts through the shoulder ribs without penetrating the shoulder blade bone. The next cut separated the shoulder and middle primal parts, and the last two cut through the chump and the middle at the last lumbar vertebrae (LLV) followed by the pre-cut on the leg separating the chump, leaving the carcass hanging on the hook. By not separating the primal pieces completely though, leaving them connected to the "back fat", the handling of the carcass back to the chill or to the next stage continued to be above floor level without the use of conveyors cluttering the passage ways. The fixation solution for this system provided the possibility for accurate cutting, especially for those cuts that needed to be perpendicular to the direction of the motion along the carcass chain. A focused project developed the fixation capabilities under a parallel project that also developed solutions for lamb and beef carcasses (BRITE/EURAM, 1993)
- the second solution from the project (Figure 4 right) performed two cuts, separating the back and the belly along the ribs vertically, also running over the shoulder ribs vertically, and then separating the long leg primal at the last lumbar vertebra. The cuts were performed with the carcass on the move supported from behind by a vertically positioned and angled moving conveyor for robotic cutting, with the robot tracking the motion of the carcass (Figure 4 right).

In 2003, when the full system was commercially installed in a pork processing plant, the butchers performing the robot cuts were allocated less physically straining jobs in the factory.

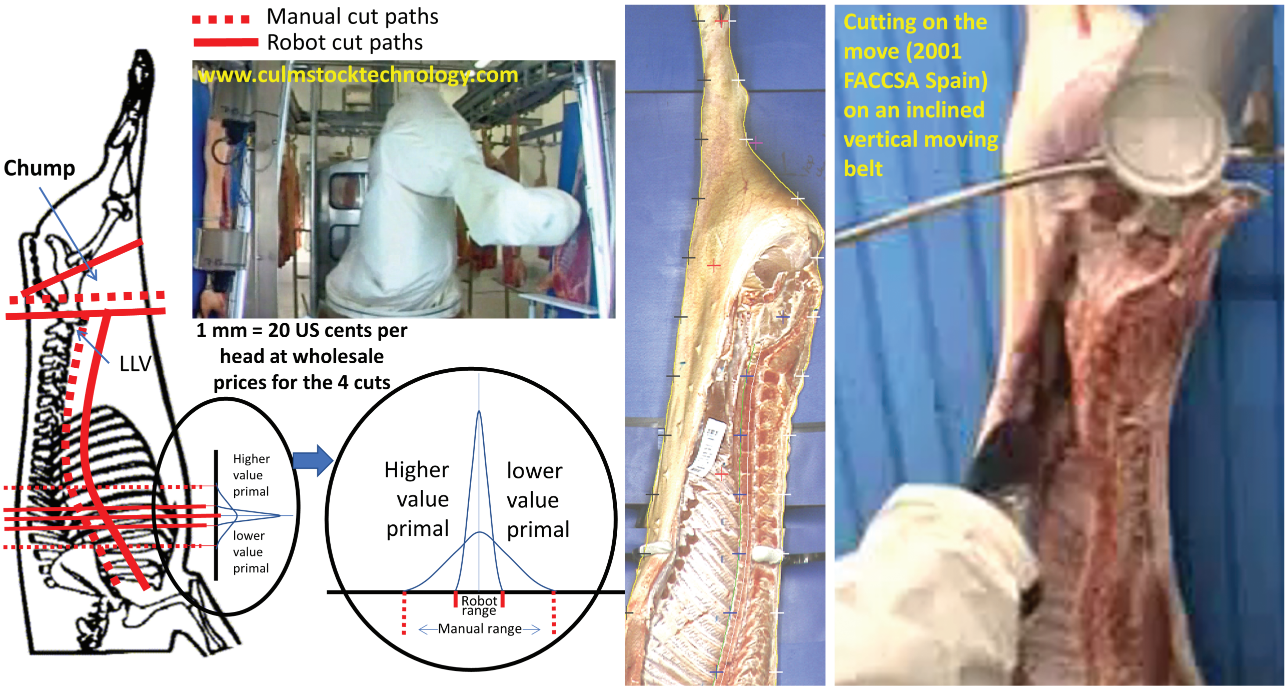

Figure 4. Robotic pork carcass cutting.

The use of robotics provided new capabilities and advantages. These are generic and relevant to many meat cutting applications and include:

- Compared to a person, the robot provides for the possibility of using a more powerful powered cutter, applying higher forces during cutting (BRITE/EURAM, 1988-91). This enables the use of new "knife-blades", designed for minimum bone dust, with the benefit of significant quality and hygiene improvements.
- The reduced bone dust on meat surfaces also avoids use of staff time to scrape meat surfaces at a later stage, especially before packaging, benefiting greater efficiency in the operation of a meat plant.
- A better work environment may be realized with the avoidance of repetitive strain in people performing such tasks, reducing work related health issues and absence.

The pork cutting solution achieved (BRITE/EURAM, 1988-91), efficiency improvements were augmented by yield optimization giving additional financial gains. Consistency and control of cut positions is achieved with robotics compared with people performing the carcass breakup. Figure 4 (bottom left graphs) shows the distribution of population of manual and robot cuts in relation to the nominal anatomical cut. The combined capability of computer imaging and robotic tool positioning following cut paths using a robot narrows the spread of the cut positions relative to the nominal position of the cut on the carcass. Consistent and accurate cut lines increase the yield in higher value primal cuts. A 5 mm cut position improvement, at 20 US cents/mm (Weblink, 2020), was estimated to achieve over US$ 300k per year (at 180 carcasses per hour over a single shift of 7.5 h per day, 5 days per week and 48 week per year). This was confirmed in the cumulative reports of yield over the first 2 years of operation. New installation may expect better than a 2-year payback period, especially when processing higher volumes than 180 carcasses/hour.

Lamb

In 2005, the lamb sector in Australia was motivated to use automation for the breakup of carcasses using robotics. By implementing the know-how and technologies developed in earlier projects (BRITE/EURAM, 1993), rapid implementation on a commercial basis was possible. Robots performed two complete cuts separating the shoulder, the middle, and the leg primal pieces (Figure 2 left). This "three-way cutting" was achieved at 180 carcasses per hour.

Unlike pork and beef, lamb carcasses are not split to reveal the spinal and rib features of the split face of a half carcass. Thus, there was the challenge to apply computer imaging to use anatomical features external to the carcass to determine cut paths that meet position accuracy and consistency expectation. The use of knife-blades, especially selected and sourced for the task also reduced bandsaw dust. The solution was achieved in record time for an installation of this kind with evaluated outcome considered more consistent compared to the manual bandsaw process in use at the time by the industry.

A follow up project achieved a new system as an upgrade to 400 head per hour (Figure 5), increasing the capability to include larger size lamb and mutton carcasses.

The project was further developed with the Meat and Livestock Australia, and Machinery Automation and Robotics Pty Ltd (MAR) Australia to perform 4 cuts (shoulder, rack, loin, and chump) at 450 per hour. Enhancements also included

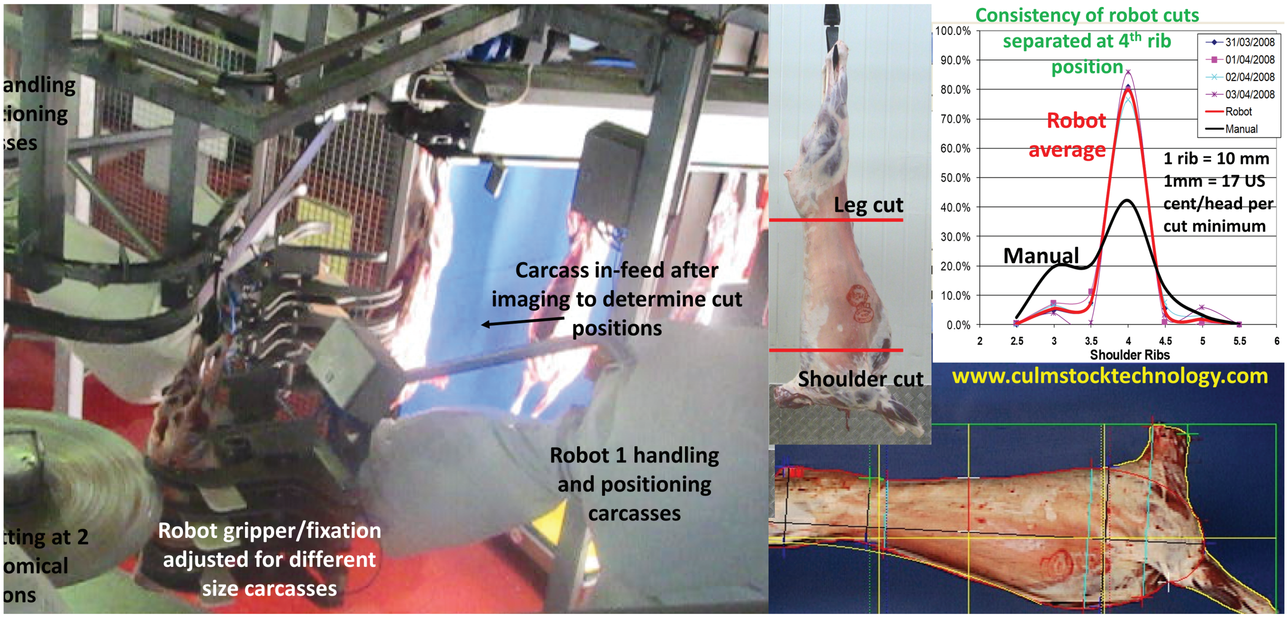

Figure 5. Robotic lamb carcass breakup (integrated with MAR, Australia).

user selection of cuts. When selecting only leg and shoulder cuts, the speed capability reached was 620 carcasses per hour (Figure 5) compared with the original 180 head per hour in 2006 (Figure 2a).

The optimization of yield in such a system can provide a capability to achieve 2 cuts with the combined additional gain of 17 US cents per head per cut per millimeter, using $85/lamb price set by processors (Weblink – blue rooster farm). For 2 cuts at 600 carcasses per hour, 7.5-hour shift, 5 days 48 weeks per year, the overall gain is US$ 367,200 for a single mm position optimization of the 2 cuts. Optimizing the position of the cut for a 5 mm correction of cut positions to improve the yield on higher value primal cuts would achieve close to US$ 1million per year, if not more.

Figure 5 shows the latest solution, comprising and in-feed system, right of the photo, and imaging system and three robots, two holding and handling each carcass on the rail and positioning for the third robot with a cutting blade to perform anatomical cuts using the vision information from an imaging system customized for this application by E+V (E+V Technology GmbH, Germany).

The powered rotary cutter blade from Freund Germany integrated used a separate automatic wash unit to make the washdown easy, avoiding contact with the blade for safety.

The estimated time for return on investment for the system would not exceed 18 months for a normal lamb operation.

Over the past decade, since the technology has been available commercially, the greater challenges for the wider industry adoption of such a solution have been availability of space for line integration and capability as well as the capacity of the plant to manage the changes and support the day-to-day operational needs of such a robot installation. At the host plant in Australia, the change process and line integration of the latest solution were successfully managed and the system reached full operational capability in less than 8 months from the time commitment to the project was confirmed. Engagement of the customer to ensure acceptance and compatibility with customer cut line requirements was essential. The awareness of all involved once the system was commissioned was key to the sustainable daily use of the robot, especially with respect to the following:

- monitoring of primal cut conformity to specification,
- documentation of performance in readiness of formal audits and Quality Assurance visits by customer organizations, involving also auditors unfamiliar with robotics,
- training and updating of operation practices, with input from responsible supply chain personnel,
- management of change supporting transition from manual cutting practices to using robotics in the day-to-day carcass breakup.

The significant challenges included the acceptance of the technology and understanding of the benefits giving rise to full ownership of the new practices with robotic in daily use. The positive steps to train all those who would need to be in contact with robots in their normal work prior to the commissioning, removed the usual reluctances, or indeed "fears" towards change in the adoption of robotics.

The combination of improved efficiency, work environment, quality and yield, and the translation into real increase in profitability and sustained supply, resulted in a recognizable positive business impact for all concerned.

Beef

Beef scribing (cutting through ribs, bone deep) and separation of major primal pieces requires the automation to accommodate a much larger range of carcass sizes as well as a wider variability in anatomical features. Use of computer imaging solutions as offered by E+V technology can locate distinct features in the split face of the carcass to allow extraction of cut lines anatomically for the control of the cut position to be optimized using robotic cutting. Figure 6 presents a set of images showing the basic approach and the typical set up for a robotic solution by MAR, Australia. The range of lines as shown in the photo to the left of Figure 6 are the main cuts which may be optimized by robotics. Two of these cuts that define the separation lines at the 12/13 vertebrae and through the ribs from as market on the photo to the right of Figure 6, can yield a minimum of 48 US cents per millimeter per head, given the difference in the value of the primal adjacent to the line of these cuts. At a nominal 5 mm in favor of the higher value primal, 400 head/hour, 7.5 h per day, 5 days per week and 48 weeks, this is close to US$ 350,000/year, using US Beef wholesale prices (Weblink 2020). Commercial systems need to target an ROI of 18–24 months for users to be motivated to invest.

The main barriers to implementation of beef solution are availability of space and the change processes for robotics to accommodate varying cuts specifications in the full range of cuts that may be performed.

R&D requires greater support from beef processors if solutions at the desired throughput rate are to be achieved, especially in the USA. Typical operations breakup 800 sides per hour and multiple cuts on each beef side, thus the need for multiple robot stations and a new handling solution, yet to be conceived and developed.

Boning and Trimming

Separation of meat from bone and different meat tissues from each other at a precise interface (generally referred to as seam cutting) requires skills of handling and manipulation beyond any robotic capability or technology that is offered by the technological advances to date. Human capability to manipulate tools and meat tissues, using only two hands is a capability considered beyond robotics, even the most advanced observed in research facilities around the world.

Human skill for separating boning from meat and trimming involves:

- recognition of the variety of meat forms or pieces;
- understanding of the characteristics and behavior of meat including mechanical, physical, and handling;
- perception of the task that includes the manner in which tools should be used
- manipulation ability, including grasping meat or bone, attachment or restraining at multiple points, holding and restraining of movement, and dynamic adaptation to both movement or forces required to restrain or cut, whilst separating adjacent tissues or meat and bone;
- determination of separation path that achieves the execution of the task in a manner that is compatible with the expected end result in relation to the specification of the two resulting pieces after each step in a boning or trimming task. In the case of deboning, the general expectation is to leave as little meat left on the bone as possible, which has complexities given the 3D shape of the bone and the fact that a butcher's knife has a 2D profile.

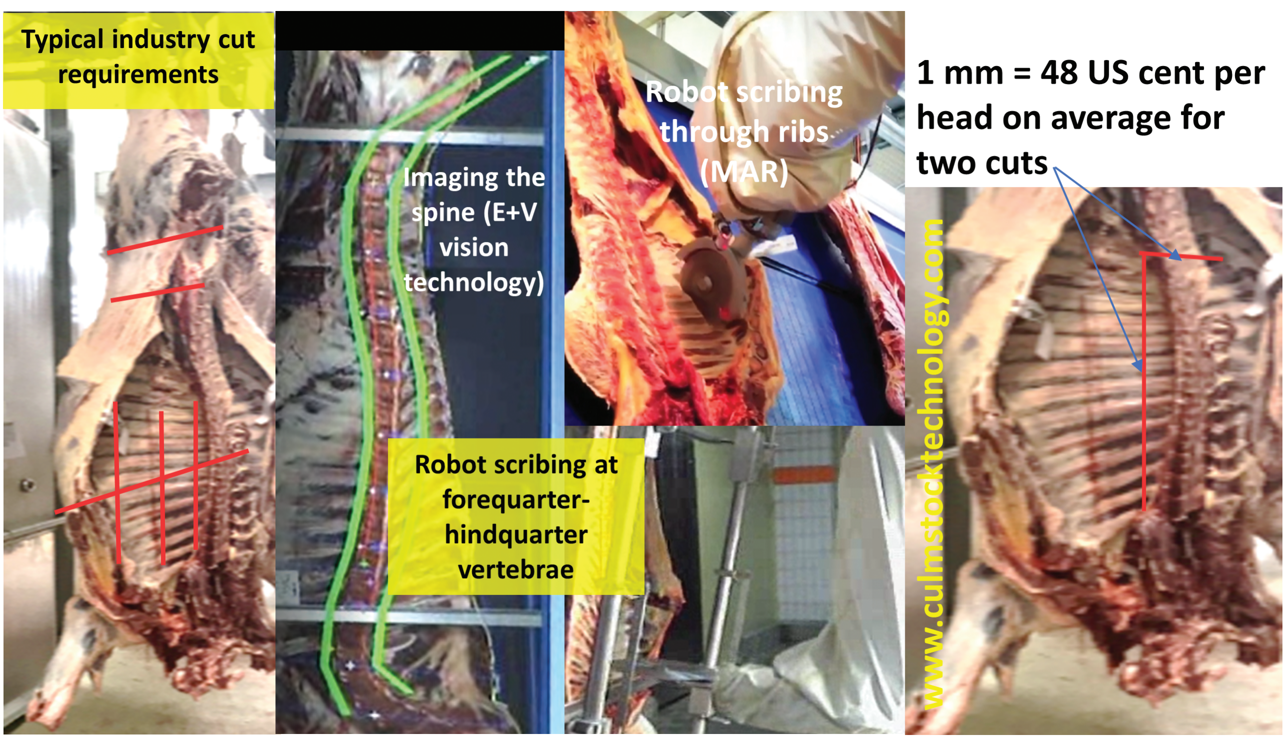

Figure 6. Robotic beef carcass scribing.

- real-time adaptation to accommodate changes during separation, including the ability to adjust manipulation parameters whilst correcting the tool movement or separation path to achieve optimum outcome in yield at best efficiency.

Bone separation

In the late 1980s (AFRC, 1987), de-boning of forequarter beef was the subject of a research program that considered the many aspects of fixation, handling, and separation focusing on the specifics of force and visual sensing capabilities for robots as well as design of appropriate robot cutting tools that may be used to perform separation of meat from the forequarter beef ribcage. The results published in the field of robotics continue to be as relevant to date as they were at the time published in the 1990s (Crooks et al., 1994; Maddock et al., 1990, and Wadie et al., 1995).

Two specific examples of robotic de-boning elaborate on the skills and potentially the approach to "engineering" the process for robotics in a manner that provides the same outcomes, and potentially better outcomes, with respect to yield and efficiency than achievable in manual operations. It is necessary to highlight that the ergonomic design of such solutions must provide for the step that presents the primal piece for robotic cutting; which is often from a preceding manual step. This preceding step, using a manual capability can provide, with the use of a specifically designed carrier (also fixing the primal), simplifications for the robotic task(s). Such has been highlighted in each example below:

Poultry breast meat separation

Figure 7 shows images of a robotic cell implemented for the boning action performed on a production line using cone fixation for carrying front halves of chicken carcasses. The loading of the front half is manual from a preceding work station that also allows the removal of skin from the front half primal piece. The loading ensures that the front of the primal is facing the robot. A series of mechanisms and sensors ensure the orientation of the primal after loading, through to the sensing station, and the robotic cutting unit, with the cone conveyor moving at a rate equivalent to 32 front halves per minute.

The skill capability achieved in the robotic solution provides the sensing and cutting process, with the knife sharpened every cycle, separating the fillet from the wishbone. Figure 7 shows the separation lines as achieved by the robot and manually. The robot capability was proven to achieve much greater consistency both in the start position of each cut, and following the wish bone edge closely to the end of the separation. The cut line of this task provides the anatomical separation for the yield or avoidance of loss of fillet meat at this interface left on the remaining carcass attached to the wishbone. Figure 7 shows the manual and robot cut comparisons with the estimated gain by robotics estimated 3 US cents (Weblink, 2020) per carcass for the combined left and right cuts performed by the robot.

At 32 front halves per minute on 4 lines, at the plant where the development took place, the estimated gain on a 15-hour shift, 5 days per week, and 48 weeks was close to US$ 830k/year.

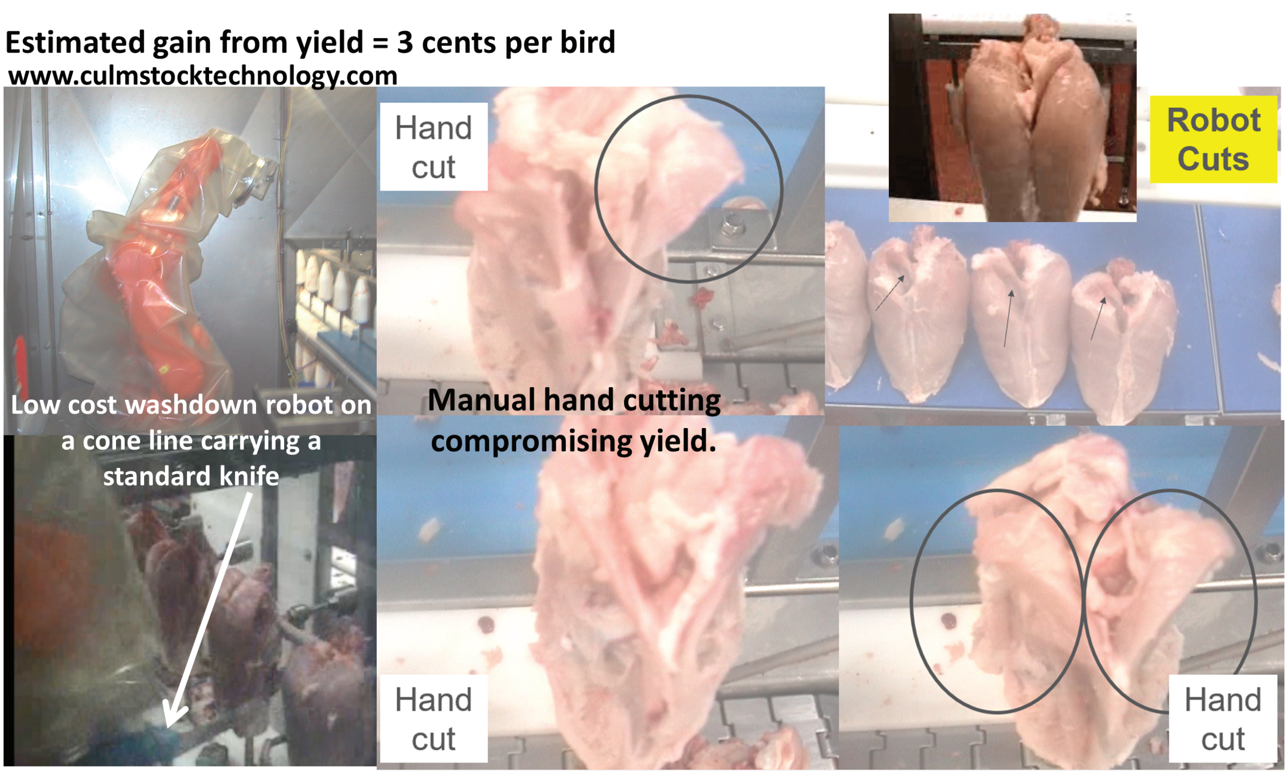

Figure 7. Robotic fillet separation at the wishbone.

The robotic capability also provides a more improved ergonomic presentation of the front half to the next stations where manual pulling and trimming is performed to a higher standard than is achieved by dedicated equipment on the market for this task. Chipped wishbone contamination being a driving motivator for robotics, which provided for seam cutting without the cutter tip coming to contact with the wishbone, whilst the cut path followed the bone profile closely. The ergonomic improvements of the process of wishbone separation leaving the fillet attached provided over 80% improvement in efficiency of the 4 lines at the user site.

Lamb forequarter ribcage separation

Figure 8 presents another highly skilled task which involves the handling and manipulation of a whole forequarter lamb primal in a two-handed operation, whilst also using a restraining arrangement to allow the pulling of the foreleg.

Running a knife against the edges of the rib bones on each side of the ribcage achieves separation close to the bone, continuing over the spinal column edge, and finally along the featherbones, achieve full separation of the ribcage carcass with little meat left on the ribs.

The robotic process uses force sensing to guide bone following, using the same approach, in a development project under an AMPC (Australian Meat Processor Corporation) supported R&D (AMPC, 2017).

The basic understanding of the technological capabilities that must be developed needs pragmatic approaches to combine with the mathematical modeling and real-time sensing and handling capabilities that increase robot skills. The challenge is also the requirement to engineer the solution for cost and compactness delivering installation that fit an approximate space foot print comparable to that used by people and at a price that is compatible with the wages paid. The project target price or a robot cell in such an application needs to provide for a 2-year return on investment. Given a US$ 50k per person employment cost on 2 shifts, the solution cost needs to fall below US$ 200k, processing one primal forequarter per minute. Work continues on this application targeting a solution that meets expectations both in performance and target commercial price.

Fat Trimming

The separation of fat from meat in a controlled manner demands high skill. The use of sensors that enhance the capabilities of a robotic solution, beyond what may be possible with people will provide distinct advantage, such as the use of ultrasonics. Another AMPC (AMPC, 2016) supported initiative targets fat trimming to leave a uniform layer on a beef striploin. Figure 9 (top right image) illustrates the challenge and possibility of the task of fat trimming a striploin where the human sensors do not actually reveal visually or by contact where the line of separation needs to be for fat removal to leave a uniform layer on the lean meat over the surface of the primal. It is perceived that contact sensing and the butchers' perception of anatomy and meat behavior,

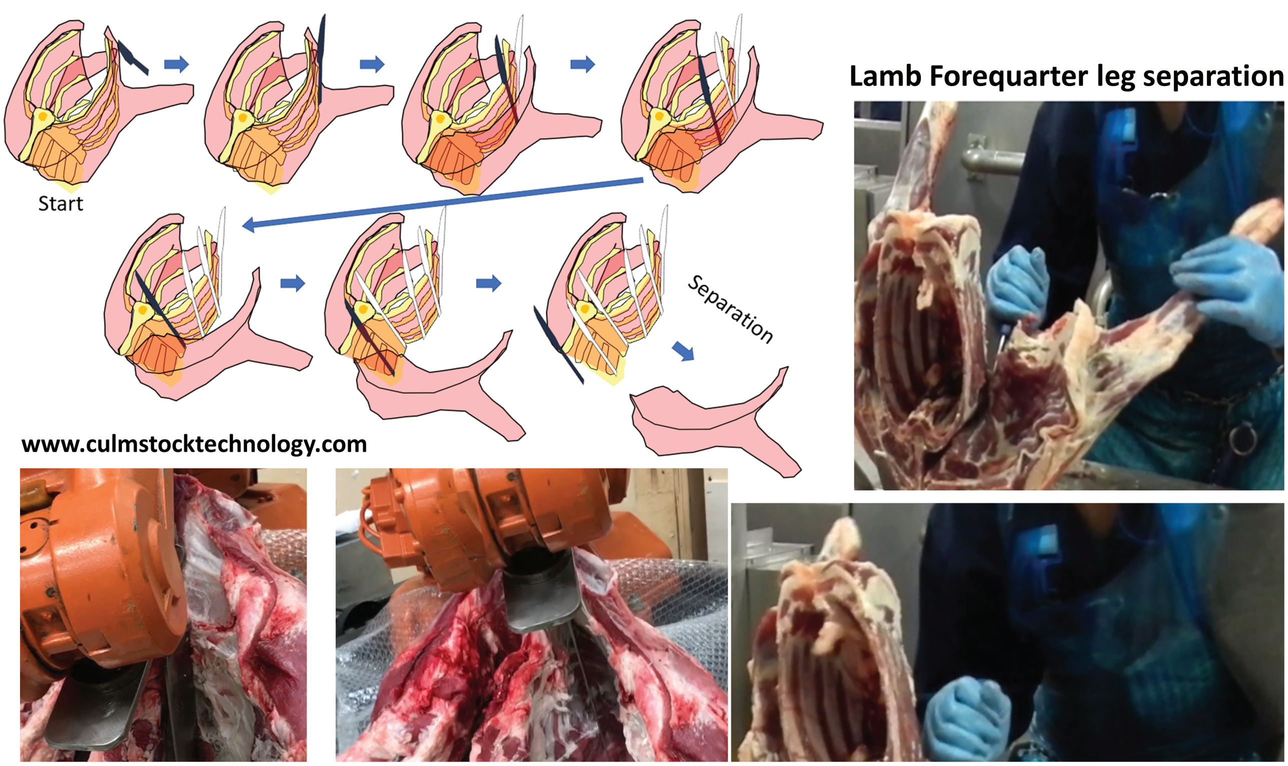

Figure 8. Lamb forequarter ribcage separation (robotic force guided bone following).

Figure 9. Robotic trimming leaving a uniform layer of specified thickness behind.

combined with the skill in knife handling provide for the capability for the manual task to be executed as best as possible. The R&D has focused on using ultrasonic sensor measurements (Khodabandehloo, 2018) to provide dimensional information locating the interface between meat and fat thus allowing a "mathematically" based path generation process within a robot program using the trajectory planning features of the embedded software to guide the tool for a more accurate separation that leaves the specified thickness of the fat on lean meat.

The motivation, other than improved efficiency and consistency in delivering fully trimmed striploin primal pieces, may be seen in the control of the thickness of fat removed and the resulting impact on yield. The wholesale value of even 1 mm of fat cover over the entire area of a strip loin is about 35 US cents or 70 US cents per animal. Given the volume of animals slaughtered each day, the numbers rapidly add up, supporting the need for R&D and commercialization.

Concluding Remarks

The opportunity for using automation and creating the benefits whilst using human skill in tasks considered beyond robotics demand not only automation solutions that perform to the same capability or better, but equally the management of change to adopt and sustainably use the technology for profit. Available commercial solutions as well as R&D that is targeting imminent new automation can deliver robotics capabilities for use in many meat plants. The extent of use and the widespread adoption requires commitment and cultural readiness, accommodating the technologies with new investments in people and innovation. Understanding how to finance robotic solutions and the change to manage procurement are fundamental successful adoption. There needs to be a clear commitment and engagement of the meat sector in the Management of Change (Khodabandehloo, 2019) if the meat industry is to tackle its human resource challenges in the coming decades, whilst expanding and attempting to be efficient for greater profitability.

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About the Author

Koorosh Khodabandehloo is based in the United Kingdom and leader in commercial robotics development since 1997. Director CT&C (UK) and RAMS (Australia). Operating internationally; personally responsible for development and first introduction to market of several ground-breaking robotic solutions in the food sector. Developments have included meat cutting, packaging, and high throughput end of line automation. Has established and contributed to the formation of several new businesses in Europe and Australia. Adjunct Professorship at the University of Southern Queensland, Australia. Founder and the Co-Chair of the International Food Automation Networking Conference (Georgia Tech, USA). Also founder and Chairman of International Meat Automation Congress. Graduated in 1982 as an electronics and computer systems engineer, Kings College London, and was a PhD researcher (1982-1985) at Imperial College, University of London. Was appointed Lecturer in 1985, age of 24, at the University of Bristol to establish research and teaching in Manufacturing Systems. Established a new MEng Degree programme in Manufacturing Engineering in 1989. Founded the Advanced Manufacturing and Automation Research Centre and was appointed its director in 1991. Promoted to Reader in 1991, followed by appointment to the Chair of Manufacturing Engineering in 1993. **Corresponding author:** kk@culmstocktechnology.com; bmcdevon@aol.com

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