AUSTRALIAN MEAT PROCESSOR CORPORATION

Automated Meat Recovery Off Featherbones

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1.0 Executive Summary

Currently the featherbones are cut off the carcass half as a "rack", thus consigning any meat in between the featherbones as a lower grade product in terms of economic recovery. If the featherbones can be cleanly separated or prised off the primal cut, leaving all the meat/gristle/fat behind, then the weight of the adjacent primal cut would be increased by this "recovered" meat.

This R&D Project was to take a close look at this task and to create concepts that might have potential for further development. The final concept would need to support a production method that would be economic based on the value of the recovered meat alone.

The initial research steps comprised:

- familiarisation for the R&D team to "get the feel" of how the featherbone is attached to the cartilage and to the meat behind it, and
- to test and evaluate sensing methods by which we could robustly and consistently identify and distinguish from each other the regions of cartilage, bone, and meat/gristle/fat.
- to try different ideas to separate the bone from the meat to see of any particular method was robust across the variations from carcass to carcass and featherbone to featherbone.
- to research any existing methods pertaining to, or potentially useful for, this task.

Conceptually, it seems that there exist 2 generic options available for the featherbone removal mechanism:

- one that relies of the individual identification of each featherbone and operates on each featherbone in turn (such as the not widely adopted manual method of an operator wielding a cylindrical cutter to cut each featherbone away from the primal cut – presumably because the operator cost versus the value of the recovered meat is marginal - we will use this as a capital cost feasibility benchmark).
- Another that is an "en masse" approach that does not require individual featherbone identification but somehow exploits the just created only flat reference surface on the entire carcass i.e. the split plane down along the spinal column and down the series of featherbones.

It is axiomatic that a method that pinpoints the location of each featherbone and acts on each featherbone individually, will employ sensing and manipulator technologies that will be complex and thus expensive (or employ a manual operator).

On the other hand, a method that references off a reliable invariant feature on the carcass half (such as the just cut plane splitting the carcass into its two halves), and somehow acts "en masse" on the featherbone "rack" is likely to be less complex and therefore less costly to automate , and perhaps faster in carrying out this function.

In this R&D Project, a number of ideas in each the "individual featherbone" or "en masse" approach were created and evaluated in preliminary testing.

For the second genre, a number of "en masse" solutions were created and tested - some being readily technically feasible and some not. However, it was found that the "en masse" solutions were not able to recover any more meat that the current method in use on the boning line, and therefore, not create a economic justification for its employment.

For the first genre, of the detection and separation (by the physical prising off - to leave all the meat with the primal cut) of the individual featherbones, we carried out tests in the two areas of individual featherbone detection from its background, and the prising away of the individual featherbone from the carcass half.

Simple conventional sensing methods were found to be not robust: vision system and colour-based methods due to the high level of variability in the appearance of the featherbones against its background, and signal absorption/reflectance methods due to the similarity of the featherbone and its background. These tests suggests that more complex and costly alternatives such as x-ray vision may be a workable alternative.

For the individual prising off of the featherbone, again the high level of variability from carcass to carcass and even from featherbone to featherbone within a carcass, presented a problem for a generic solution. Even if a workable featherbone prising off method was developed, such a method would entail the employing of a dexterous and flexible handling mechanism such as a robot.

From the body of implementation experience, a Robot Cell that used x-ray detection and a 6-axes robot to carry out programable movements would cost in the order of $400k to $500k (after the Prototype development).

Consequently, it was determined that none of these ideas had the potential that the recovered meat would to give a capital payback within a year, and therefore, investigations should be terminated with this minimal expenditure Stage 1 assessment study, at this time.

2.0 Introduction

This project was approved by the Australian Meat Processors Corporation Ltd (AMPC) to search for practical and cost-effective machine concepts for the automated meat removal off featherbones. Therefore, the objective was to create a cost effective automated or semi-automated method to remove the featherbones while leaving behind all adhering meat in a presentable appearance. As such, this detached meat would effectively add to the weight of meat in the primal cut.

The Stage 1 Part of the Project therefore had an objective to create effective and practical machine concepts, carry out bench testing to prove the concepts, and based onto successful tests, the successful concepts would underpin the creation in the next Part - Stage 2 - of a practical automated machine design, estimated performance parameters and a budget cost for a production machine. Stage 3 will tender a final report on this R&D Project.

An initial concept was formulated following a discussion and demonstration of featherbone separation by Darryl Heidke of the MLA. After observing Darryl's manual method to release the meat off the back of a featherbone, we envisaged that a robot held gripper tool can be designed to simulate this action. That is, to break back the cartilaginous distal lump at the end of the featherbone and then to force a cleaving (not cutting) tool down between the bone surface and the meat, thus exploiting the weak bond at this interface surface between meat and bone, to prise the bone off the meat.

The tool was envisaged as a triple-fingered device in which the two opposing outer fingers would grip the featherbone, while an offset middle finger would break back the cartilaginous distal lump and then move down the length of the featherbone separating the meat...

Such a tool can be powered but hand-applied or ultimately, with vision sensing of the position of the featherbone, be robotically applied.

2.1 Project Preparations

The initial research steps comprised:

- familiarisation for our R&D team to "get the feel" of how the featherbone is attached to the cartilage and to the meat behind it, and
- to test and evaluate sensing methods by which we could consistently identify and distinguish from each other the regions of cartilage, bone, and meat.
- to try different ideas (including Darryl's) to separate the bone from the meat to see of any particular idea was promising
- to research any existing methods pertaining to, or potentially useful for, this task.

To this end, each week we purchased from our local butcher, a section of the rib cage comprising the split featherbone to the ribs across, and about 6 to 8 featherbones in length.

3.0 Project Objectives

The objectives were to firstly, find a method for sensing the featherbone amongst its surrounding meat and secondly to discover the best way to remove the featherbone from the surrounding meat while leaving the meat undamaged. With this knowledge as a foundation, the ultimate goal was to develop a design concept that would make the task of removing the featherbone more practical, cost and time efficient.

4.0 Sensing the Split Featherbone

Towards the first methodology genre, we carried out tests using known sensing methods to try to distinguish between bone and meat/cartilage/fat and thus to enable the mapping out of the featherbones from the meat on this split face of the carcass half.

Because the bone that we are wanting to detect has been split, what is exposed to the sensors is the "boney" fibrous structure inside the bone which looks like and is coloured like meat (rather than the hard whitish "boney" outer shell that one sees on a French dressed rib.)

4.1 Vision System

There appears to be significant variations in appearance of the featherbone on this split surface from one carcass to another.

Over some 10 samples that we have studied, there are samples where the "meat" in between the featherbone is actually whitish coloured fat and therefore the reddish granular structure of the inner featherbone can be readily distinguished by its colour difference. In other samples, the material in between the bone was a very similar colour to the reddish granular structure of the inner featherbone, and therefore almost indistinguishable by the Vision System. In addition, sometimes there is a smearing of blood over the entire surface - this would also blur what differences in colour there may be.

When there exists a distinct piece of cartilage attached to the end of the featherbone, and it is clean, the white cartilage can be easily seen, however, the presence of this piece of cartilage and its visible colour contrast, is not consistent over different carcass samples, or even from featherbone to featherbone within one carcass sample. In other words, we found that this cartilaginous lump is not always present.

After testing with a Vision System we came to the conclusion that this will not be a reliable method for distinguishing the featherbone from the meat in between.

If there was a consistent height difference between the featherbones and the in-between-meat (as is evident on the inner surface of a rack of ribs), then a Vision-based method such as “structured light” would see the corrugations formed by the bones, but since our surface has been just split by a bandsaw, this surface is perfectly planar.

4.2 Methods using differences in reflectance and absorption

For many applications, we have utilised sensors that deploy a specific wavelength of light – visible or non-visible – that reflects off certain materials and yet is absorbed by another different material. For example, a strip of clear cello tape can be distinguished from the object to which the tape is affixed, not by any colour difference, but by the different way that cello tape absorbs say infra-red light that is projected onto it, versus the way the background material absorbs this wavelength of light.

We thought that the “boney” structure inside the featherbone and the meat/fat in between the featherbones might possess different absorption characteristics to different wave-lengths of light, but tests with off-the-shelf infra-red sensors, ultrasonic sensors and laser sensors did not show useful or reliable differences.

It could be that there exist a specific wavelength in the infra-red or ultra-violet range of the spectrum that may be more useful, but this would entail spectral absorption analyses, and in our experience even if a specific useful wavelength was found, the building of such a be-spoke sensor is very expensive, and likely to be very cumbersome.

5.0 Methods that utilise the only flat plane on the carcass

The just-split plane through the spinal column and the featherbones is the only flat plane on the carcass half.

Special properties of this plane are:

- all the featherbone halves lie within a slice that is about 12mm thick above this planar surface, and
- the line where the outer edge of the carcass half intersects this cut plane i.e. the outer skin ridge above the tips of the featherbones is a reasonably consistent and predictable distance away from the tip of each featherbone.

Therefore, if the split plane of the carcass half was pressed against a flat reference surface, then

a. all the featherbone halves would lie within say 12mm above this planar reference surface, and secondly,
b. a line can be drawn (detected visually) where the dorsal edge of the carcass meets/sits on this reference surface. At a fixed distance into the carcass from this line would define the tips of all the featherbones.

Can we use these 2 pieces of information for our purpose?

5.1 Idea One

We could press the just-cut face of the carcass half against a reference plane, and then a planar saw cut can be made at some 12mm above and parallel to this reference plane. This cut will separate a 12mm thick slice of the carcass – within this slice would contain all the featherbones and a slice of the spinal column.

We have checked with our local butcher on how he now separates the meat primal cut from the featherbone. He tells us that he does something very similar i.e. make a cut to separate the meat from the featherbones by running the knife hard up against the featherbones along the length of the carcass (and down to the spinal column), and then to bandsaw cut the remaining ribs to effect the final separation of the featherbones and the spinal column from the primal meat cut.

The question is: how much meat would be wasted in our proposed slice that contains the featherbones and spinal column? It appears to us that often in between the featherbones the meat, if any, is largely fat and gristle.

We would need to consult industry experts to assess the viability of this Idea One.

5.2 Idea Two

A variation on Idea One is that instead of cutting off a parallel 12mm slice that contains the featherbones, we use a cleaving (i.e. not cutting) tool biasing down onto the featherbone to prise the meat off the featherbones as this tool is pushed the length from the tip of the featherbone to its root next to the spinal column.

The advantage of Idea Two is that the meat is prised off the featherbones leaving all the meat/fat/gristle behind. However, getting the cleaving tool to the point where the meat/bone interface (the natural plane of weakness) starts is not easy - this is the same as Darryl's method to break off the cartilage first and insert a cleaving tool to do its work in this natural plane of weakness.

Our experimentation has shown that cleaving too early in the cartilage does not direct the tool into this natural plane of weakness (between the featherbone and the meat).

For the cleaving tool, we have tried

- a plain passive blunt chisel. This chisel must be of a similar width to the featherbone, otherwise a wider chisel cuts into, and is held back by, the meat on each side, but it does prise the featherbone cleanly off the meat, but requires a reasonable force to drive the chisel between the bone/meat interface. The challenge here is how to get this blunt chisel tool into position at the bone/meat interface inside of the cartilage tip lump before we can start the prising action along the length of the featherbone.
- a percussive blunt chisel (longitudinal oscillations), as seen in *Figure 5.1*. This chisel must be of a similar width to the featherbone, otherwise a wider chisel gouges into the meat on each side. A narrow percussive chisel does naturally follow the "weak-point" interface between the featherbone and the meat and prises the featherbone cleanly off the meat with little force, but where and if it cuts into meat, the meat cleavage surface is of torn meat (and not presentable without cleaning up with a manual second trim cut). Again, the challenge here is how to get this percussive blunt chisel tool into position at the bone/meat interface inside of the cartilage tip lump before we can start the prising action.
- a vibratory cutting chisel (lateral oscillations), as seen in *Figure 5.2*. This cutting tools cuts effectively into both bone and meat, and does not follow the "weak-point" interface between the featherbone and the meat, and therefore needs to be actively steered to give the desired plane of cutting.

Figure 5.1: Air Chisel

Figure 5.2: Vibratory cutting chisel

We have also tested Darryl's method of pressing down on the cartilage lump to break it away from the tip of the featherbone, but found this method inconsistent:

- in some test samples we could not see a white cartilaginous lump at all,
- in other samples we did identify this lump and we could break it away from the tip of the featherbone by pressing down on it,
- in yet other samples, we could not break away this lump even by hammering on it with metal punch!

For Idea Two a possible method to create an entry point for the prising tool is to make a knife cut slit from the skin to the position on and above the featherbone where the featherbone/meat interface begins (Figure 5.3), so that subsequently a prising tool inserted to this point can carry out its prising action without having to get pass the cartilage lump first.

We can do this by placing the carcass half, split featherbone face down, onto a reference surface, and to make a knife cut into the meat surface so that a continuous slit, of say 75mm depth, enters at the skin surface above the tip of the featherbone, and angles down over the cartilaginous lump and onto the top surface of the featherbone. This slit would run the entire length of the carcass, entering the carcass half, skin side, at 20mm above the reference surface, and be parallel to the reference surface along the carcass half. Using this pre-cut entry slit, we can use a wide blunt percussive chisel to work down along this slit to progressively prise the meat off the featherbone.

Figure 5.3: Knife cut slit for chisel entry

However, when testing this concept we found that the percussive chisel while cleaving the meat from the featherbone (Figure 5.4), actually tears the meat that bridges between the featherbones (Figure 5.5), making a very untidy looking severance surface on the face of the primal meat cut (that will need a cleaning up trim cut - which will not gain a net saving in labour).

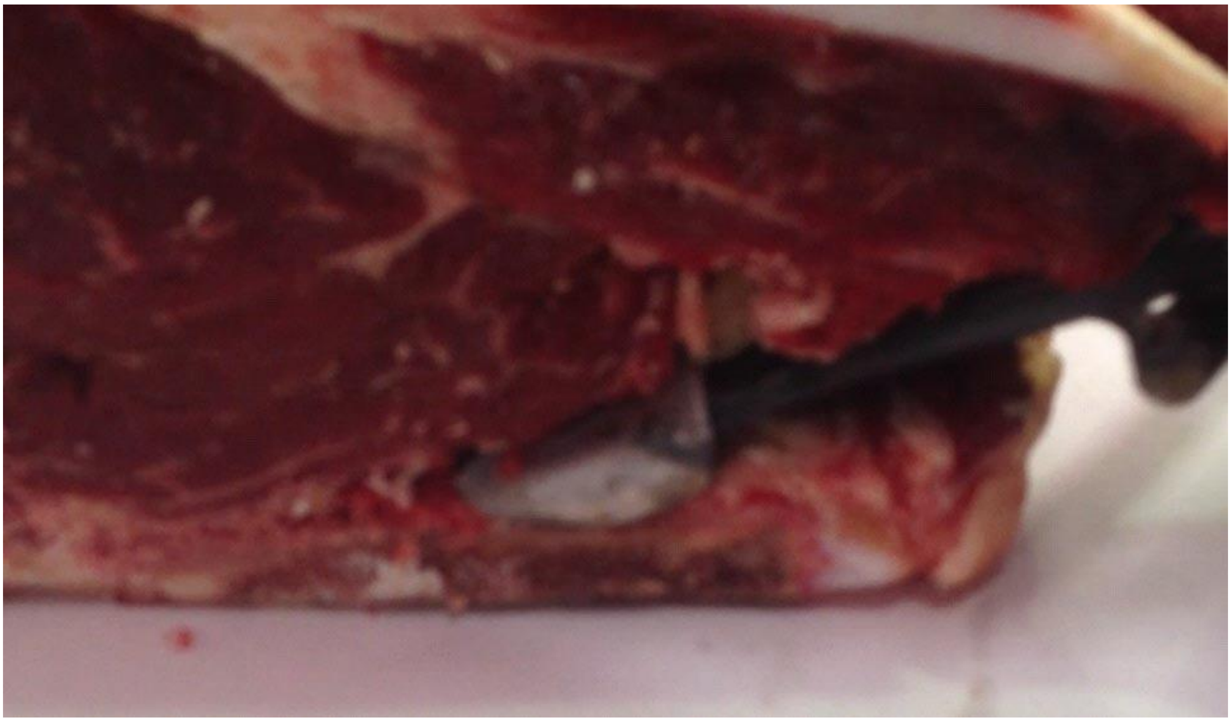

Figure 5.4: Percussive chisel removing meat

Figure 5.5: Bone prised off meat using percussive chisel.

5.3 Idea Three

This idea is derived from Idea One, which was to make a knife cut between the featherbone rack and the primal meat cut, biasing the knife hard up against the featherbones. This is similar to the first operation the butcher carries out to separate the primal meat cut from the panel of featherbones and the spinal column.

Idea Three proposes that at one step back in the abattoir de-boning process, instead of splitting the carcass down the central spinal column and featherbones to obtain the two carcass halves, we do something different.

This is to make two parallel cuts – one on each side of the spinal column and featherbones. What we would get as a result would be:

- Two slightly smaller carcass halves, each cut off at the featherbones and primal meat cut interface, leaving a clean cut exposing the cube roll and the cross-sections of the ribs below that.
- One central slice of the carcass (about 25mm to 30mm thick) that contains the full featherbone panel and the full spinal column. A potential secondary advantage of making this central slice is that the spinal column is left intact so fully containing its neural matter, so avoiding the possibility of spinal column matter contamination of subsequent meat cuts (and the need for any R&D projects to develop better methods to clean out this neural matter!)

Perhaps, the two parallel cuts are not parallel but actually tapered into each other at the tip of the featherbones - such a "toe-ing in" of the two cut planes would better move the cut planes against the featherbones to save more meat.

This parallel cuts process can be readily implemented now, manually by the carcass splitting operator.

Alternatively, a robot manipulating a single blade bandsaw could perform this splitting cut provided the robot was given the cut trajectory by some sensing method.

Or a twin bladed bandsaw, with an automatically adjustable "toe-in" of the cut planes could be developed so that by a single cut the robot would create the two carcass (reduced) halves and the central spinal column/featherbones slice.

Again, we would need to consult industry experts to assess the viability of this Idea Three.

6.0 Methods that attack each featherbone in turn

We have highlighted the problems in a reliably automated detection technology to sense each split featherbone in the carcass' just-cut plane, even though manual operators do not have this problem.

Perhaps, more complex technologies, such as x-rays or tailor-made sensors can be brought to bear on this problem, but as always, cost constraints will be a limiting factor, as the potential savings of any featherbone meat removal method is only in the meat that might be recovered as a higher value product.

We have searched the literature for existing featherbone removal methods, and have found:

- the US-designed "featherbone buster" power assisted grapple tool which has one jaw that hooks in behind the spinal column and a second jaw needs to hook in behind a few featherbones. Once so positioned, its power actuation will close its jaws so cleaving the featherbone away from the meat. However, getting the second jaw into position behind the featherbone tips will be problematic - as we have found. This tool has been trialed in Australia but was abandoned (because it was too difficult/awkward to use?).

- the IBEX circular powered trimming knife from New Zealand. This hand-held air-powered cylindrical blade, rotary cutter is hooked behind the distal tip of the featherbone and is moved inwards toward the featherbone base cutting away and separating each featherbone from the meat. Because of the shape and fixed diameter of the rotary blade, the cut-off piece is a part of a cylinder, and this part of a cylinder contains the featherbone half and some meat surrounding it - the meat cut off along with the featherbone is wasted with the featherbone. Also, as the featherbones gets smaller in size and is increasingly swept-back towards the rear of the carcass, it gets more difficult to apply this fixed diameter cutter to each featherbone.

Alternative methods to tackle individual featherbones that we have tried were:

- burrowing a curved (30mm radiused), 25mm wide, 3mm thick metal blade with a sharp front edge but blunt side edges under a single featherbone, at its centre and at right angles to the bone's long axis. This was a relatively easy operation for a manual operator who could readily see the demarcation between the edge of the featherbone and the meat in between, also, the meat here is soft. Once this curved blade was hooked under the middle of this still attached featherbone, the curved blade is dragged laterally left towards the spinal column and right towards the tip of the featherbone, to employ its blunt side edges to cleave the featherbone away from the meat. The blunt side edges would simply prise the featherbone away cleanly from the meat and leave all the meat behind (this is an advantage over the IBEX tool which cuts away meat along with the featherbone). While this work well under the featherbone proper, when the curved blade reached the junction between the featherbone and the cartilaginous tip, even a high force failed to break the cartilage tip away from the featherbone.

- Another concept that is related to the above-mentioned curved blade idea, splits the curved blade into two opposing halves with each blade half entering under the featherbone from each side. Imagine a pair of standard pincher tongs (used for grabbing onto the head of a nail and then pulling out that nail by rolling the tongs on one of its curved jaws). Such a pair of pincher tongs, equipped with appropriately shaped and sized and curved jaws would be used to burrow under the featherbone at its mid-point from both sides, and once closed under the featherbone be used to physically pull the featherbone away from the meat. We envisage that each curved jaw might be some 60mm wide so that it applies the pulling force over a significant length of the bone.

All of the described concepts in the Section 6.0 above, requires a consistently successful and cost-effective method to detect the featherbone half within the split carcass half (which we have not found) and in addition, they all require a robot to manipulate the tool to perform the featherbone separation, while another mechanism holds the carcass half in place. Even if a cost-effective featherbone detection technology was available, it is doubtful whether or not the savings in meat recovery would justify the cost of the technology. Again, we would need to consult industry experts to help us assess whether or not this particular direction is worth pursuing.

7.0 Expert Review

We were at a point at the end of Stage 1, of needing to know if any of the above described ideas is attractive for practical use, or has potential for further exploration. We therefore suggested that this is the time for a discussion meeting with experts in the field (before we proceed to the development of a specific concept in Stage 2).

Following the tabling of the above Stage 1 Report, we indeed received the opportunity to bounce the included ideas off a panel of Abattoir Technology Managers, during an AMPC R&D Steering committee meeting in North Sydney (3rd December, 2014).

Basically, the consensus view was that prising the featherbone off the meat was the only options otherwise the reduced recovery of meat (through freeing the featherbones by cutting) would not pay for the automation.

Thus, the cutting free of the featherbone panel en masse options would not recover enough meat for an economic return.

Furthermore, the twin cuts to each side of the vertebrae idea (Idea Three) which suggested the benefits of non-contamination by spinal cord matter by keeping the spinal column intact, was impractical in that the removal of even the spinal column half would sufficiently weaken the entire carcass half to make it more difficult for the subsequent de-boning operations. Also, the issue of spinal matter contamination control is not a regulatory one, but a “good practice” one for optional adoption by each abattoir.

8.0 Conclusion

This then leaves the individual identification and location of each featherbone, followed by its individual prising off from the carcass as the only option with an acceptable economic return.

As was discussed in Section 4.0, where we tested a number of technology options to sense and locate the split featherbone within its background of meat/gristle/fat, simple and lower cost solutions using sensors and a colour vision system were not effective in the face of similarity of appearance of the featherbone marrow and the surrounding meat/gristle/fat, and the large variations of the appearance of the featherbone and its distal cartilaginous lump due to physical differences between one carcass and another.

Our conclusion was that the 2D X-ray vision was perhaps the only reliable option to detect and locate each featherbone from its background. Actual x-ray vision tests have not been carried out at this stage, but reference to the body of work already gathered together by the AMPC on x-ray detection of bone within a carcass, should confirm the technical feasibility of this method here. X-ray has the possibility to make technically feasible the task of individual featherbone detection on the carcass half.

However, once the individual featherbone has been detected and located, it then needs to be individually prised from the meat – this implies a dexterous action that is tailored to each featherbone. This in turns implies a 6 axes robot equipped with a featherbone prising tool.

Even without specific details of the featherbone prising or cutting tool, or how the carcass is held and stabilized during the featherbone sensing and prising process, it is clear from both your own and Applied Robotics' body of implementation experience of such a Robotic Cell, that the installed cost of such a Cell, will be in the order of $400k to $500k (after the Prototype development).

The consensus is that at this order of cost there will not be sufficient savings in recovered meat to justify the expenditure.

Consequently, it was jointly decided not to incur further expenditure on R&D, but to complete this Concepts R&D stage at this point with this Final Report.