final report

Project code: P.PIP.0071

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Date submitted: August 2006

PUBLISHED BY
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Fresh meat (trimmings) belt inspection system

This is an MLA Donor Company funded project.

Meat & Livestock Australia and the MLA Donor Company acknowledge the matching funds provided by the Australian Government and contributions from the Australian Meat Processor Corporation to support the research and development detailed in this publication.

Executive summary

Applied Sorting Technologies (AST), in association with Rockdale Beef Partnership (RB) and Meat & Livestock Australia (MLA), has developed a novel x-ray inspection system targeted at detection of small bone fragments in beef trimmings travelling at production rates along boning room conveyor systems. A prototype machine has been built and tested and found in boning room trials to be able to detect hard bone down to about 2mm thickness with very low false reject rates. Ways of potentially improving the system from both a detection point of view as well as making a more practical machine for boning room duty have been considered.

Contents

1 Background

The red meat industry has considered it important to work toward achievement of low (preferably negligible) occurrence of bone fragments in their product to both overseas and domestic customers. This is especially serious in the case of trimmings destined for grinding/mincing where the fragments could be distributed throughout hamburger and similar product. Existing x-ray and other intervention techniques presently in operation in meatworks have been unable to detect bone fragments much under 10 – 15 mm minimum dimension.

Preliminary theoretical work funded by AST at Monash University Centre for X-ray Imaging suggested that hard (skeletal) bone may be detected down to a vertical minimum dimension (thickness) of down to 1mm in red meat trimmings lumps of up to about 70mm thickness. From previous work undertaken by AST, it was evident that the industry-required rates of around 5tph could be achieved on conveyor belts around 600mm wide at speeds of around 30m/minute with meat lumps of a single layer deep (monolayer). This was based on AST’s experience with engineering of x-ray machines currently inspecting carton meat for contaminants such as shotgun pallets in export abattoirs.

The project was carried out over a number of stages, from elaboration of theoretical models, through experimental work in AST’s laboratory, to development of detailed design for a first plant-operatable prototype inspection machine, construction of that machine and factory and eventually boning room testing. Appropriate milestones were achieved before proceeding from one stage to the next.

Reports have been issued on completion of the various project stages, so only the salient points from these are mentioned in this final report, and the reader is referred to these stage reports for more detail.

Three sets of boning room trials were run at RB, the last being a systematic set of tests arranged by Rockdale technical staff. These were run with various bone types and sizes. This last set of trials is reported in detail below. The first two sets of tests were reported in project notes of 7th April and 3rd May 2006 respectively.

The conclusion after analysing the results of the last tests is that the prototype machine is capable of detecting hard bone fragments down to around 2 – 3mm thick of max dimension above of around 5mm with very few false reject rates (under 0.2%), and under 2mm thick bone when allowing slightly higher false positive rate around 0.3%. These tests were carried out with meat pieces packed onto the conveyor so as to simulate throughput rates of around 5tph.
It has been evident from the initial stages of the project that soft (flexible) bone/cartilage was unable to be detected to any useful degree due to lack of x-ray contrast arising from lack of mineral content which is needed to differentiate it from meat.

Possibly the limiting factor in the machine’s implementation has been the size of detectors and alignment of the dual detector arrays. The detector pitch was 1.5mm. We suggest that possible improvement may be by way of use of single beam configuration with energy-selective x-ray detectors of the type that are just now becoming available. This system would have the added practical and important benefit of using much lower x-ray flux, thus making a smaller machine without the need for elaborate x-ray shielding. This would aid in successful implementation in the confined spaces generally available in boning rooms.

The energy selective (pulse detection) method of measurement has been discussed in a related MLA project carried out recently by AST (Investigation into DEXA Techniques for On-Line Carcass Yield - A Report to Meat & Livestock Australia Ltd - Project No. SCT.021, 14-5-06). Since the issue of this report, the author has visited the leading detector manufacturer in the US in June of this year and as a result, AST is making arrangements to procure a trial pulse detector array for scoping experiments.

2 Previous Stages of the Loose Meat Project

The project has developed through a number of stages with hurdles which needed MLA authority to proceed to the next stage. These stages are summarised below.

Stage 1 – Development of Detection Specifications – Report of 3rd October, 2003

Achievement of full characterisation of low-energy x-ray detection via AST/Monash model for selected bone/cartilage types in muscle/fat tissue as well as definition of essential equipment for the measurement phase.

Stages 2 and 3 – Laboratory Experimentation for Contrast and Image Processing Requirements – Report of 27th January, 2004

Demonstration of contrast requirements appropriate for target product/contaminant combinations, and demonstration of automatic contaminant recognition via computer image processing of x-ray images with realistic processing capability.

Additional Stages 2A/3A – Report on Basis Material Decomposition Tests – 31st May, 2004
This was an agreed extension due to the promise of a large contrast improvement between bone and meat when employing a medical-developed procedure called in the medical literature Basis Material Decomposition. It involved processing two separate x-ray images of the same sample using two x-ray beams of different energy content.

Stage 4 – Report on Design of Plant Pilot Machine – 12th November, 2004

This phase provided details of machine design using two x-ray beams and detectors, and included details of means for belt removal and cleaning and other machine features.

Stage 5 – Laboratory Testing of Pilot Machine – January, 2006

The pilot machine was available for testing in January 2006. Indicative tests were carried out with RB on a limited amount of trimmings to verify broad performance criteria and determine that the machine was sufficiently promising to proceed to the stage of testing in RB boning room. The machine was moved to RB in March, 2006.

Stage 6 – Testing of Machine in situ at Rockdale Beef

Two sets of tests were carried out in April and May respectively with a significant amount of software optimisation being carried out between these two sets of tests to further improve the system. The use of "movie" mode incorporated in the operating software allowed continued work on the recorded test runs on an off line computer running the same Loose Meat program. The runs were able to be replayed on computers at AST as if the x-ray signals were coming directly from the actual detectors on the machine. This enabled a number of the software image feature extraction techniques to be used on the same set of bone/meat lump data. Short reports on these tests were issued on 7th April and 3rd May, 2006 respectively.

Following the meeting on 10th July between AST, RB and MLA at Rockdale, it was decided to defer installation of the pilot machine on the production trimmings line due to the engineering cost required to make the changes to the boning room to accommodate the machine in its prototype form.

Instead, it was decided that RB would devise and carry out a series of systematic tests to characterise the machine performance and produce a set of "movies" of a significant number of runs with meat and bone fragments. These tests were carried out on 28th July and resulting movie files sent to AST to develop a performance envelope in terms of bone detection and false positive levels.

In addition it was decided to consider what changes may be able to be made in a possible new configuration which might yield both an improvement in bone detection and compactness necessary to suit typical cramped conditions of Australian red meat boning rooms.

3 Systematic Boning Room Tests

Trials carried out on site at RB on the 28th July, 2006, have been processed by AST in order to map performance capability for the prototype machine. Refer to Attachment I: Bone Description & Experimental Protocol for details of the bone and meat pieces used for the trials.

About 15kg of beef trimmed to less than 70mm thick pieces was used for each of 45 test runs. There were about 40 individual pieces in each run. The photo here shows typical feed belt loading for one of the runs. In total there were about 1845 individual meat pieces which were passed through the machine at an equivalent rate of about 5 tph.

Six groups of bone fragments (designated A to F) were used, each bone fragment being attached to a lump of meat for a particular run, with tests of each bone type being repeated seven times. For each run there were 3 introduced bone pieces labelled large, medium and small. Dimensions are set out together with photos of each bone used in Attachment I.

During analysis in Melbourne, a number of settings were used to build up a picture of performance in terms of successful bone detection versus false positives. The results are set out in Table 1 attached. They are laid out in order of false positive rate, from zero to 2%. During the analysis, different parameters were varied, each parameter potentially altering the balance of bone detection and false positives.

The specific detection parameters varied were as follows:

1. Material Enhancement Factor

This is the Basis Material Decomposition-derived angle used when reconstituting the x-ray image from the high and low energy constituent images. Small changes in this angle from 89 to 90 degrees cause significant changes in bone/meat contrast, resulting in generally better detection, but more false positives.

2. Morphology Level, L1

Lower L1 parameter results in more blobs being present in the image. Blobs are defined as discrete regions of interest detected on limps of meat which are characterised by dark edges. The blobs then have to be classified according to a set of rules to then predict whether they are positively identified and hence separated.

3. Maximim % Transmission

This is one of the morphological (regional) tests. The system relies on bone being of lower image intensity than the surrounding meat, so once regional blobs have been defined within each meat lump by the L1 morphology process, each resulting blob is measured for average darkness (called % transmission) and blobs darker than Max % Trans are considered bone and marked with a red outline around the blob. Blobs which are lighter than the set limit have yellow boundaries and do not trigger rejection of the associated meat lump.

Blobs determined by this process as potentially bone cause activation of suitable lump separation devices. These could include robotic fingers with meat pick up determined by belt timing and lump location from the x-ray image.

4. Object Erosion Size

This parameter is applied to the outer boundaries of each meat lump (shown in the displayed image as a green boundary), to move the region being analysed in from the lump boundary to reduce sensitivity to edge effects.

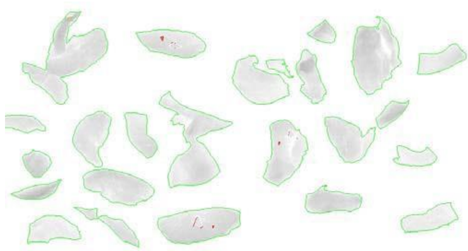
5. Min Blob Pixels

As the name implies, this parameter allows for some size filtering for “blobs” where small irregularities may be filtered out. Having this parameter too high may effect very small bone detection.

4 False Positives vs Bone Sensitivity

A large amount of experimentation with parameters was carried out in order to give maximum bone sensitivity with minimum (preferably zero) false positives. Although not totally exhaustive, a combination of parameter settings was found where no fps were generated. Subsequent groups of settings were graded in terms of increasing bone sensitivity and fps. Several of the above-listed parameters could be changed independently to alter this balance.

Portion of Run D5, showing 3 bones detected Auto Tags Off (upper image) and On (lower image)

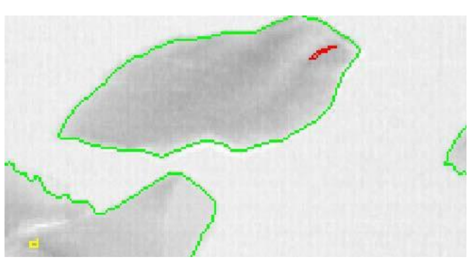


The 3 seeded "D" bones have a small wire loop next to them for identification. The bone fragments are graded from largest size (DL) at the top of the image, medium size (DM) in the middle, and smallest (DS) at the bottom.

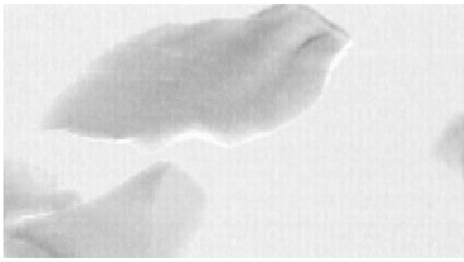
It can be seen from Table 1 attached that for a setting that has no false positives in 1845 lumps, the following bone fragments were detected

- all "**A**" bone fragments (thickness dimension ~2.3mm),
- all 14 "**DL** and **DM**" bones (thin feather bone) between 2.0 and 2.8mm thick,
- 4 of 7 "**DS**" bone (1.7mm thick),
- 17 of 21 of "**E**" (cartilage cap with central layer of hard bone) between 4.9 and 6.4mm minimum dimension (thickness),
- all of "**CL**" (8.7mm thick soft round bone).

Small needle bone ("B") between 1.6 and 1.7mm thick was detected 20 of 21 times with settings allowing less than 0.3% false positives. However the "F" series – bone slithers of mainly cartilage were only occasionally detected, even up to a sensitivity which gave rise to 1.5% false positives.



Although the meat pieces in these tests were cut from primals in order to avoid the possibility of bone fragments mistakenly occurring, the occasional false positives were in some cases very similar to bone fragments – the x-ray image here (shown with red auto tags on and off at the left) is an example. In order to avoid tagging this and a few similar examples, it was necessary to reduce the sensitivity somewhat, resulting in lower detection success in "B" (small needle bones) and "C" (soft round bones) examples.



It is possible that a slight spatial misregistration between the high and low energy beams may have contributed to the formation of ridges of darker “blobs” which intruded into the “bone” region of the morphology settings.

5 Prospects for Improvements

Whilst the current prototype has demonstrated capability of hard bone detection down to very small fragments, at times below 2mm, without excessive false positives, a possible improvement on the current arrangement may be achieved by use of the novel technique of x-ray photon counting detectors. These detectors may achieve a couple of desired outcomes. In particular, they would use only a single x-ray beam, so there would be no spatial misregistration, and also from a practical plant implementation point of view they would dramatically reduce the x-ray power required for good detection. This would help reduce false positives and would make shielding against x-ray scatter much easier to achieve without separate conveyor structures and in a shorter belt length than the current machine.

At the same time, the photon counting detector system has the ability to simultaneously measure a number of separate x-ray energies instead of just two as in the current machine, and this may assist in reducing the influence of variability in meat lump composition. It may allow extrapolation to the measurement of chemical lean values of the individual lumps.

This technique has been discussed by us recently in another MLA project concerning the measurement of carcass yield on production chains. Although the detectors involved would be significantly more expensive that the detectors in the current machine, this would need to be balanced by the savings in component cost of the low power x-ray source compared with the current double high power source, as well as the smaller cabinet with reduced x-ray shielding.

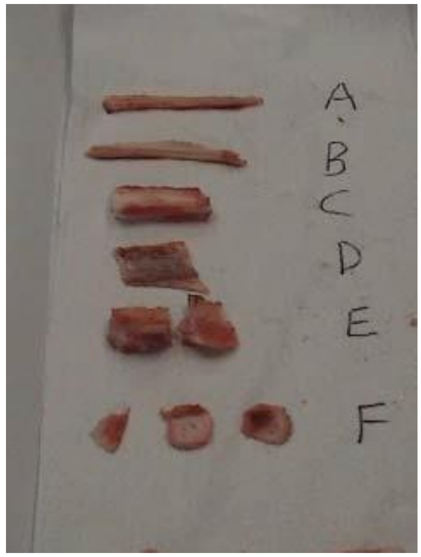
The prospect is that the this detection technology would be expected to yield a machine with better detection performance whilst being easier to integrate into current boning rooms without major line changes.

6 Conclusion

A novel x-ray inspection system has been developed to assist the Australian red meat industry reduce the incidence of bone fragments occurring in trimmings product.
The resulting pilot machine has been tested in the boning room of Rockdale Beef, and has demonstrated capacity to detect hard bone down to a thickness of around 2mm. This performance is believed to be significantly better than machines currently on the market.

It is recommended that consideration be given to further development of the system in order to improve its ease of installation and ultimate spatial resolution by investigating the use of recently available photon-counting x-ray detector arrays.

7 Attachment 1 - Bone Descriptions and Experimental Protocol Description



A	Large needle Bone-Very hard long thin bone	
B	Small Needle Bone-Very hard long thin bone	
C	Soft round bone	
D	Feather Bone-Very hard thin brittle	
E	Cartilage cap with very hard bone in the middle	
F	Bone Slither- Thin bone, mainly cartilage with small layer of calcification on surface	
AS		5.21x3.48x2.36
AM		4.93x4.08x2.27

AL		6.01x8.09x2.27
BS		2.71x3.92x1.57
BM		3.44x4.77x1.69
BL		4.21x8.17x1.66
CS		6.37x9.89x4.74

CM		10.73x14.6x5.69
CL		10.94x15.54x8.74
DS		6.54x7.29x1.68
DM		5.98x11.53x2.02
DL		8.89x14.79x2.77

ES		11.16x19.19x4.92
EM		15.50x15.56x5.12
EL		9.41x22.81x6.41
FS		11.66x16.2x2.23
FM		14.89x19.41x4.16
FL		17.35x22.27x4.44

Experimental Protocol

1. Processor warm up for full 24 hours
2. X-Ray and conveyer warm up for 6 hours
3. Bones selected, cleaned and photographed
4. Bones cut down into small fragments and measured (Small, Medium, Large)
5. Bones secured in cello tape and labelled. Cello tape had metal hook threaded through for attachment and point of reference on X-Ray.
6. Samples were photographed.
7. Primal's collected off the belt and cut down to trim size (smaller than 700mm tall)
8. Belt was loaded with 15kg of beef each time. The small fragment was attached to the meat at the bottom, the medium in the middle and the large at the top to make the assessment easier.
9. Photo taken of belt layout.
10. The video was engaged and the belt run.
11. This was repeated 7 times for each bone type
12. For the slithers, the bones were aligned flat along the meat for the first 5 runs and then lengthwise for the next five runs to assess the effect of orientation of a small bone volume