final report

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JBS Automated Rib Cutting – Detector Upgrade

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Abstract

The Robotic Rib Cutting System is an R&D system developed by SCOTT and installed at JBS Dinmore. A key part of this system was the development of an X-Ray system capable of scanning the ribs for beef sides with a wide variety of lengths and weights. This consists of individual X-Ray hardware and custom-built detector for the low-energy and high-energy beams. After monitoring the system, it became apparent that the high-energy/low energy detector has degraded and requires an overhaul as well as additional measures to extend part life. After upgrading components on the detector, the performance was successfully restored to its original levels. Further measures were also implemented to improve the lifetime of the detector moving forward. This work provided key learnings for the application of x-ray sensing in the wider red meat industry.

Executive summary

The Rib Scribe module is the first of the LEAP4Beef modules developed by Scott and MLA at JBS Dinmore. At the time of development the system was the first beef scribe cell to utilise x-ray imaging to position rib cuts accurately. Similar to the lamb LEAP system, being able to measure the internal anatomical features of the carcase is crucial in achieving an accurate dissection for each carcase. The original x-ray system was developed by Scott AST physicists and x-ray technicians as a custom solution to suit the specific application found in imaging beef. This involved developing a custom detector capable of dealing with the challenging nature of beef carcases – namely large variation in sizes and thicknesses across, and within carcases.

As this was the first system of its kind and the technology was in the early stages of development it has been found that there is a deterioration effect in the signal received from the detector which was impacting directly on cutting accuracy and machine performance.

Building on the learnings from this previous work and our experience in the LEAP lamb automation Scott have devised a way to upgrade the detector to address the issues being seen with detector degradation.

The detector upgrades were successfully designed, manufactured, and installed. The results from the re-commissioned system demonstrate the level of performance from the detector has been restored successfully.

Early indications are that the response of the detector is robust and accurate and will provide a good basis to underpin the operation of the machine to specification.

It is anticipated with the design modifications that the detector will last significantly longer in the field and ultimately achieve a lifecycle that is expected of plant capital equipment such as the Rib Scribe machine.

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1 Background

The robotic rib cutter is an R&D system developed by SCOTT and installed at JBS Dinmore. A key part of this system was the development of an x-ray system capable of scanning the ribs for beef sides with a wide variety of lengths and weights. This consists of individual x-ray hardware and a custom-built detector for the low-energy and high-energy beams. After monitoring the system, it has become apparent that the detector has degraded and requires an overhaul as well as additional measured to extend part life.

The custom x-ray system was developed based on extensive trialling data as well as pre-existing know-how from developing x-ray inspection systems. A key part of this is the custom-built detector. The system, including x-ray response, has been monitored throughout production.

Each detector consists of two calibration signals, the 'fullscale' signal which is the response when the x-rays illuminate the detector with no object, and the 'offset' signal which is the response when no x-rays illuminate the detector. A properly operating system has the response shown in Fig. 1, where the number of bad pixels is small and isolated and can easily be dealt with software corrections. When the system is in distress the response is typically depressed, where there are too many bad pixels. These bad pixels are tagged primarily due to a lower than normal or non-existent offset signals, a characteristic of detector x-ray damage.

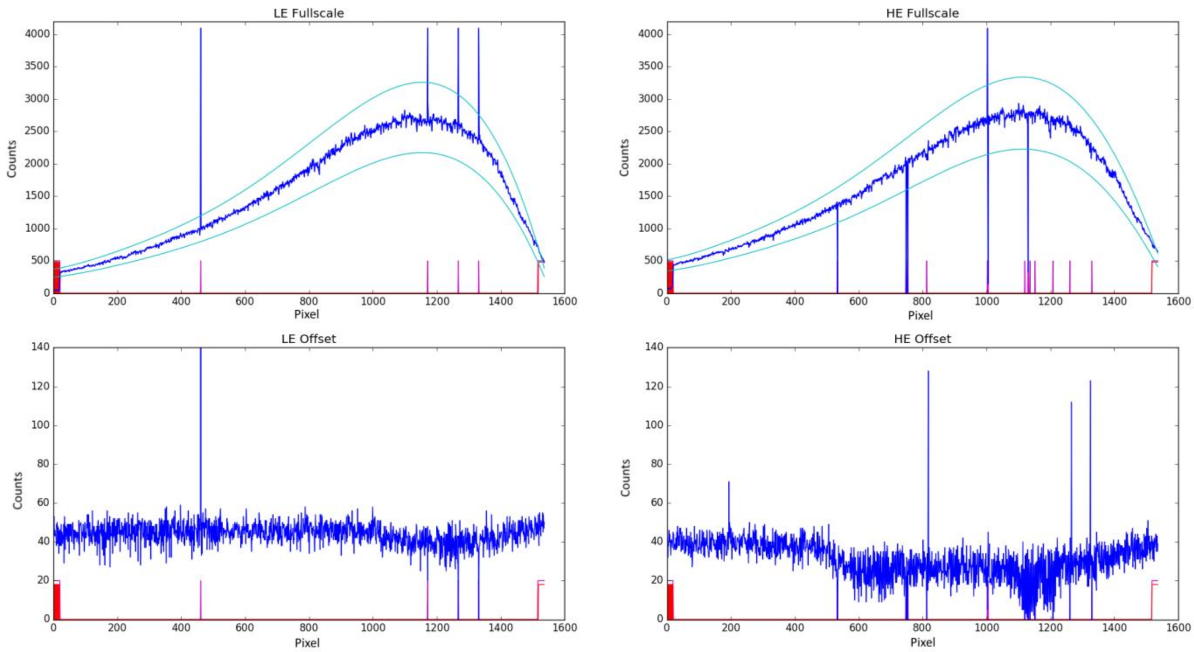

Fig. 1 X-ray detector response during December 2014

2 Project objectives

The overall objective was to design and configure the x-ray component of the LEAP system so that for any future installations the upgraded components are included to ensure the system is more robust.

The specific objectives are:

1. Design a pilot system upgrade small section of detector and evaluate the detector performance using phantom scans.
2. Design an alternative pilot system upgrade to larger detector upgrade and evaluate the detector performance using phantom scans.
3. Design an alternative pilot system upgrade to upgrade additional detector components and evaluate detector performance using phantom scans.
4. Report on the commercial finding and recommendation for future x-ray design and build.

The provider (Scott Technology) will supply a JBS company specific report and a general industry report detailing the commercial detailed specifications for the required changes to the hardware and/or software for the x-ray upgrade.

3 Methodology

Past experience had provided enough evidence to suggest that deterioration of detector performance is due predominately to radiation damage. This is reflected in the structure of the proposed upgrade. The final upgrade plan was broken into stages in an attempt to minimise disruption to production and to evaluate whether modification did indeed rectify the problem. The system performance after each stage was assessed to evaluate if the next stage was necessary. In short, there were 3 stages:

Stage 1:
This stage consisted of restoring the performance of the detector by replacing a portion of one of its primary components. The enhancement was so good that it triggered the activation of stage 2.

Stage 2:
This stage consisted of replacing half of the remaining components to future proof the system. During this process, a drop in x-ray intensity was observed and could only be attributed to a misalignment of the geometric configurations of some components. To rectify, the entire system was re-aligned, checking the locations and orientations of the detector, conveyor belt, shutter, collimator and tube. The enhancement was so good that stage 3 to investigate another detector component was not required. It was concluded that it would be better to instead change all the instances of the primary component in the detector. Therefore, stage 3 was modified accordingly.

Stage 3:
This stage was re-tasked to replacing all the instances of the primary component in the detector to future proof the system by ensuring the entire detector begins a new life with no radiation damage.

Stage 3 - Additional:
To extend the life of the x-ray detector additional measures were implemented to minimise the amount of radiation experienced by the detector.

3.1 All Stages – Phantom Test

For all stages, recording the x-ray response before and after detector modifications would be sufficient to decide if the modification was indeed successful. Though, a more robust test is to make comparisons of the detector response using a phantom test piece. By choosing appropriate materials, the collected images are processed to create reference data that are used to enhance the contrast of bone in x-ray images, making it easier for the image analysis software to more accurately detect the location of the first rib. This test was carried out when deemed necessary.

To use the phantom, a new rigging had to be designed and manufactured to allow the position of the phantom in the positions shown in **Error! Reference source not found.**. The phantom rig is ounted onto the rib-cutting robot by removing existing saw, as shown in **Error! Reference source not found.**.

3.2 Stage 1

This stage involved the following tasks:

- Phantom test before change and capture x-ray images.
- Access to detector enclosure.
- Change a few of the damaged primary component.
- Cleaning detector components.
- Check supporting hardware.
- Check detector enclosure sealing and close the lid.
- Capture testing x-ray images.
- Phantom test after change and capture x-ray images.
- If required we will also work on new image contrast enhancement calibration.
- Test system before production and available at site on the first production day.

Once these tasks were completed there was a major issue with humidity which affected the detector response. Past experience has shown it necessary to keep the air-conditioner on in the cutting room. Unfortunately, during the shut-down period, the air-conditioner in the transfer tunnel was turned off and had a major effect on the environment in the cutting room. Once the air-conditioner in the transfer tunnel was turned on again, it took some time before the environment stabilised and the first convincing improvement in detector response were observed.

3.3 Stage 2

This stage involved the following tasks:

- Phantom test before change and capture x-ray images.
- Access to detector enclosure.
- Change more of the primary component.
- Check detector enclosure sealing and close the lid
- Capture testing x-ray images
- Phantom test after change and capture x-ray images. Two different phantoms.
- Creation of new calibration.
- Test with limited sides and ramp up trials.

Once these tasks were completed the detector response was lower than expected. After a thorough investigation it was concluded that a complete x-ray alignment of the system was necessary.

3.4 Stage 2 – Geometric Alignment

The extension of stage 2 was necessary due to unexplained changes to the geometric alignment of the x-ray system.

3.5 Stage 3

This stage involved the following tasks:

- Phantom test before change and capture x-ray images.
- Access to detector enclosure.
- Change remaining instances of primary component.
- Check detector enclosure sealing and close the lid.
- Capture testing x-ray images.
- Phantom test after change and capture x-ray images.
- Creation of new calibration.
- Test with limited sides and ramp up trials.

3.6 Unnecessary Irradiation

Additional changes were implemented to the x-ray system to minimise the amount of radiation encountered by the detector without compromising performance. It is expected these changes will further improve the life of the upgraded detector.

4 Results and Discussion

The success of the changes implemented in this project can be determined by evaluating the following results.

4.1 Detector Response

The detector responses before and after the modifications were analysed. The most significant feature noting that radiation damage has been removed is the vast improvements in the 'offset' response.

4.2 Calibration

Once all the modifications were completed, the bone-contrast enhancing calibration was performed again. In Fig. 2, the left image shows a carcase processed with the newest calibration data whereas the right image shows a carcase processed with an older calibration data. The left image is better than the right image on two counts:

1. There are less artefacts, as shown in the red box.
2. The first rib is more visible, even though this carcase is bigger.

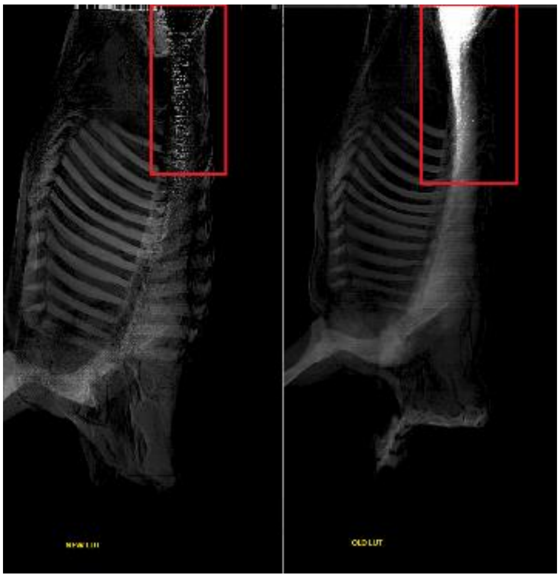

Fig. 2 Bone enhanced carcase images before and after modifications.

4.3 Other Factors

The effect of humidity on the x-ray detector is significant. Not only must it be minimised inside the detector casing during normal operation, opening the case in a high humidity environment can significantly delay re-establishing good detector response.

4.4 Reduction of Detector Irradiation

It's expected that detector life will be improved by approximately 200% of its initial life.

5 Conclusions/recommendations

The detector for the automated beef rib cutting system has been successfully upgraded. The signs of radiation damage have abated and the system has returned to full production with performance greater than that achieved at the initial site acceptance testing of the machine. Additional measures were implemented into the system to enable longer detector life moving forward. The learnings from this project will be adopted for future x-ray systems in the red meat industry.