milestone report

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Abstract

The Project will conduct a scoping study to determine whether a dual-view X-ray scanner using multi-energy detectors, combined with hyperspectral and and visible band colour cameras, can be used to identify defects and abnormalities during screening of red and green offals.

This Report will provide an update on the following:

- Methodology, data and analysis, outline of algorithms, and technical feasibility for this application.

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1 Performance Period 3

1.1 Milestone 3

1.1.1 Scope Program of Work

The program of work has been scoped to:

- Design and build a bespoke Rapiscan 60x40cm, 160keV X-ray scanner.
- Install commercial Hyperspectral imaging cameras and illumination into the tunnel of the X-ray scanner.
- Electromechanical integration of the two camera systems with the base X-ray system.
- Develop software to integrate the two camera systems with the base X-ray system.
- Define histopathological abnormalities and defects in offals: type, location and size.
- Capture images of a range histopathological abnormalities and defects in offals from the multi-sensor system.
- Development of image fusion and classification algorithms for the offal abnormalities and defects.

1.1.2 Hardware delivery

The bespoke 6040DV scanner was delivered to the Melbourne site in late October. The scanner was delivered with conventional, dual energy detectors installed for initial test and integration work.

Photos show the compact format of 6040DV scanner.

The multi-energy detector suite was delivered and installed mid-Dec.

Side-by-side comparison of dual-energy (left) and multi-energy (right) detector boards. The line of x-ray detection is horizontal across the lower part of the board.

Finally, the pair of cameras (one in the visible spectral range and one in the short wave infrared spectral range) were delivered New Year's Eve.

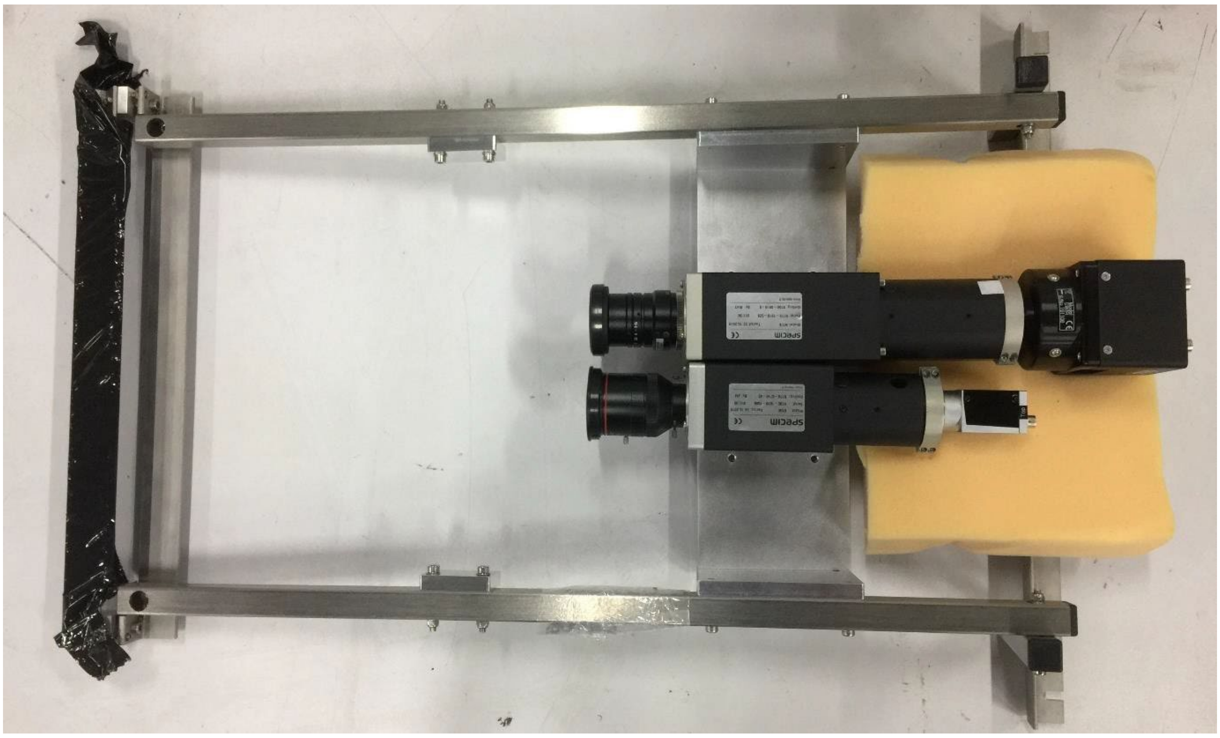


Photo of the pair of hyperspectral cameras on mounting bracket.

2 Project objectives

The program shall deliver against two key objectives:

- **Objective 1:** Utilising the Rapiscan 6040DV-ME dual-view MEXA system to screen offals for agreed defects and abnormalities.

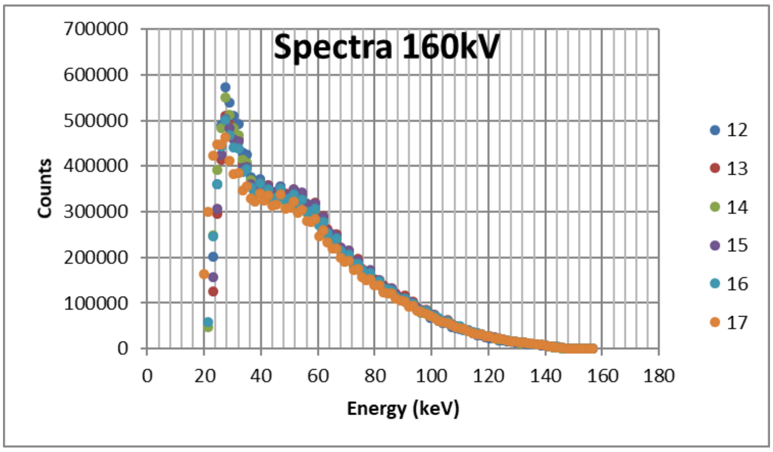
- **Objective 2:** Develop an addition to the Rapiscan 6040DV-ME dual-view MEXA system to include hyperspectral and colour imaging in addition to X-Ray to screen offals for agreed defects and abnormalities.

2.1 Hardware

2.1.1 6040DV scanner operation

The final activity with the 6040DV scanner hardware has been to fully furnish the U-view (up shooter) with ME detectors and optimise for imaging the offal in its tray.

The figure shows an example of the ME detector boards intensity signal at each of the six energy levels (six different colours. The energy levels range from low energy (~30keV, blue) to high energy (>120keV, brown).

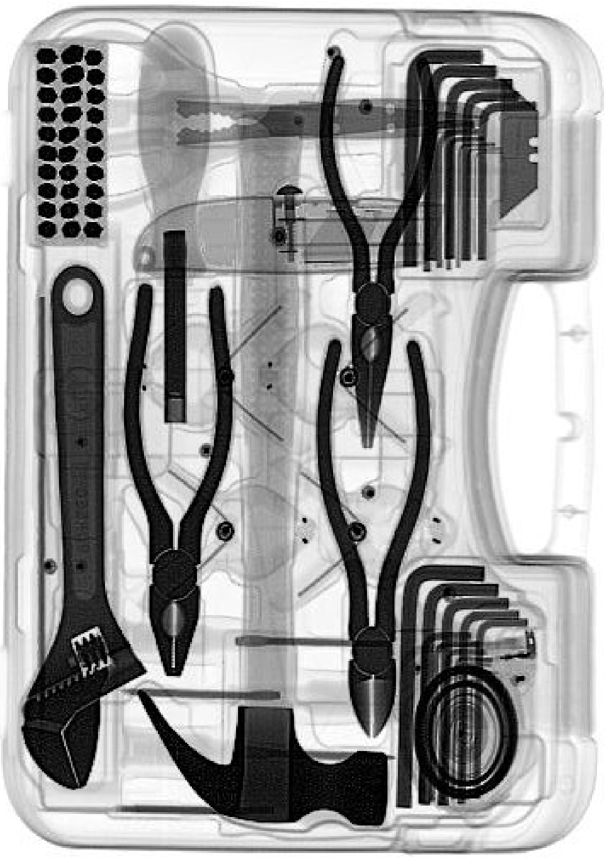


The 6040DV x-ray generator spectrum across a number of image pixels. The best x-ray image contrast is at the lowest energy, where the count rate is highest.

2.1.2 6040DV scanner performance optimisation

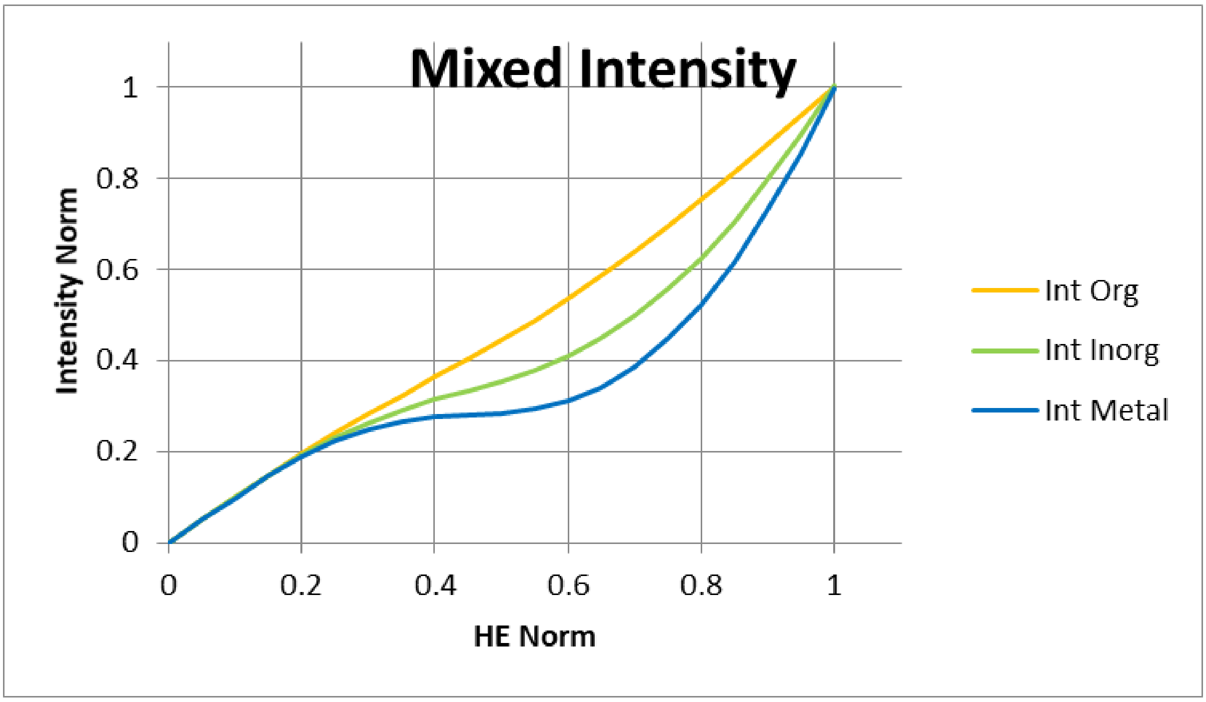
While much detail is contained in the spectrum above, in operation it is desirable that the presented image is optimised. This optimisation process takes the six ME image inputs and presents the best image contrast for either an operator or machine vision for segmentation and identification. An example is displayed below.

Low energy image (left) showing high contrast (e.g. low-density plastic case), but little penetration into high density tools, and high energy image (right) showing lower contrast (e.g. of low-density case), but high penetration (e.g. high-density metal tools).



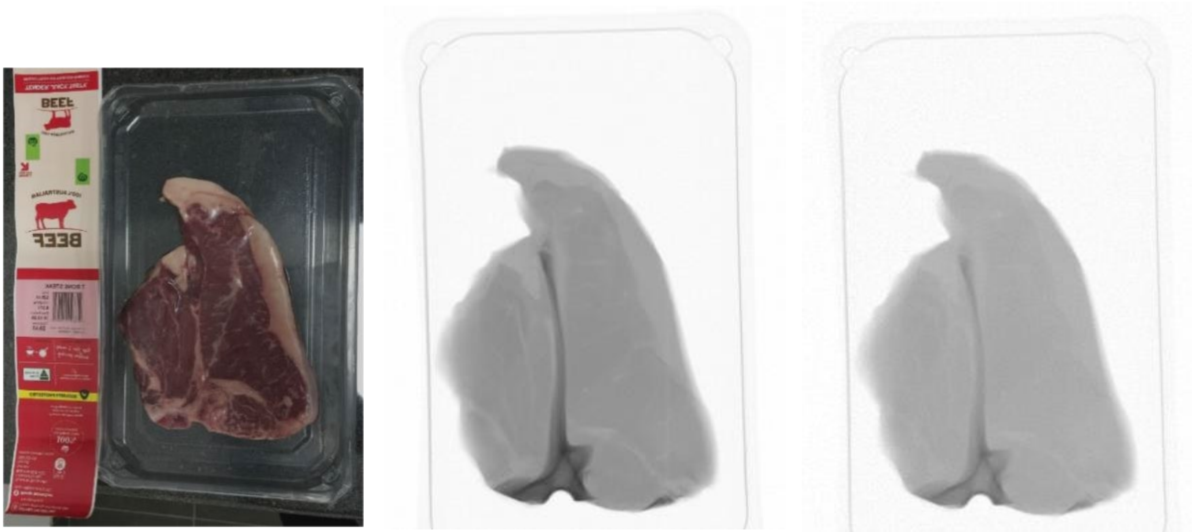
Mixing the low energy and high energy images appropriately, we get the best contrast of each. Note, the detail in the hammer head (high density) and grip (low density).

An example of this mixing is shown below. In this example, organic material approaches a linear response, which is best for offal screening contrast.

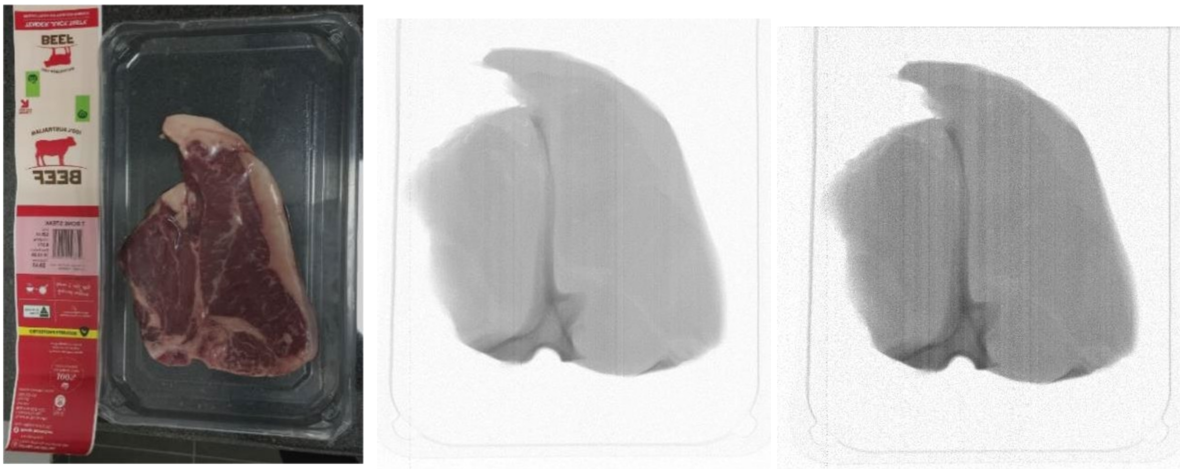


2.1.3 X-ray image outcomes

Example image outcomes for the DE and ME x-rays are displayed below.



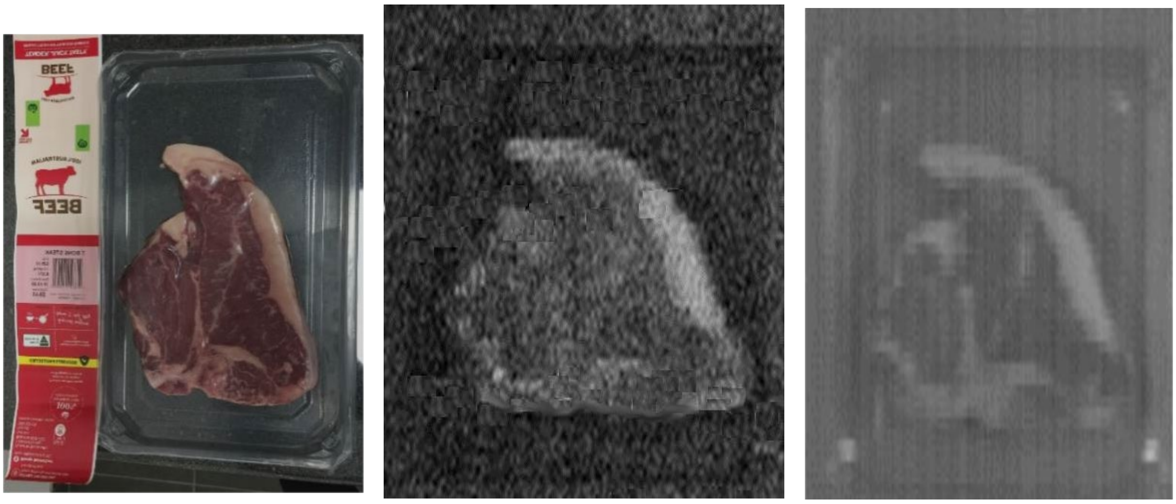
Dual energy images of a T-Bone. Low energy (middle) and high energy (right). Clear segmentation based on image contrast for fat, lean and bone is possible in the low energy image.



Equivalent imaging with ME detectors. The x-ray images are from one low energy and one high energy band of the available six.

2.1.4 Hyperspectral camera optimisation

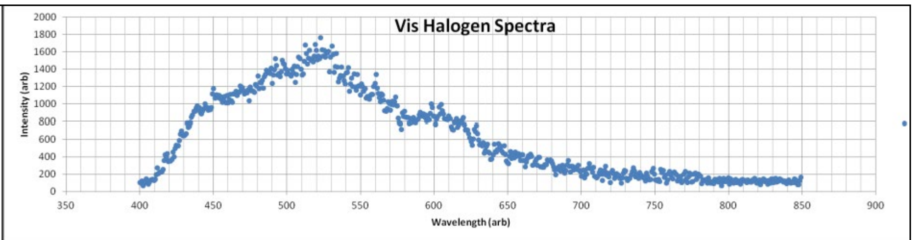
The hyperspectral cameras have been installed into the 6040DV. Lighting is a major part of the camera performance. For example, the equivalent T-Bone image for the Visible and SWIR cameras under operating conditions are shown below. The hyperspectral images lack the fidelity of the x-ray images, both in noise and resolution. Improved lighting was needed.

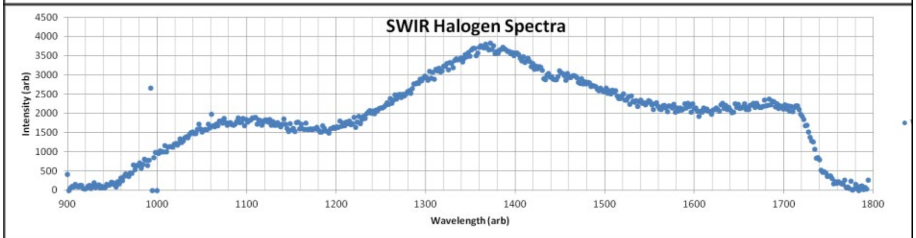


Images of the T-Bone from the Visible (middle) and SWIR (right) cameras.

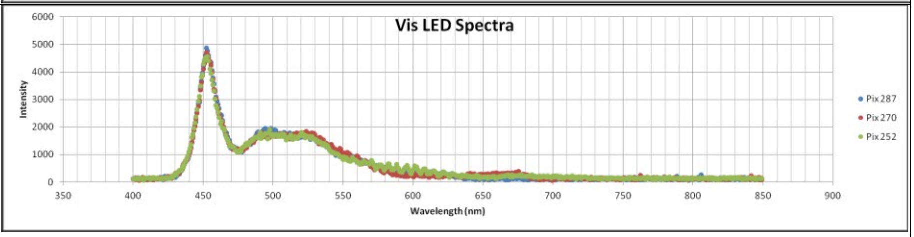
A range of lighting sources were tested. Example spectra are shown below. It is desirable that the light source have both spectral range and high intensity.

Halogen Downlight

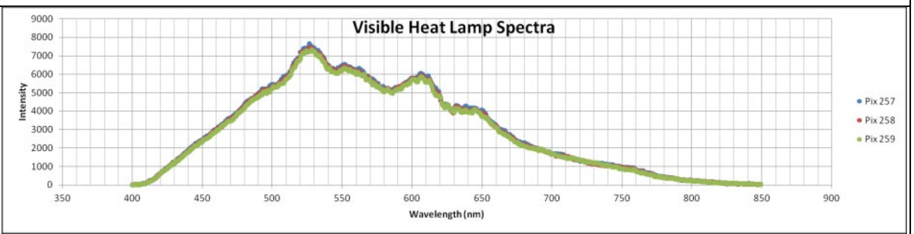


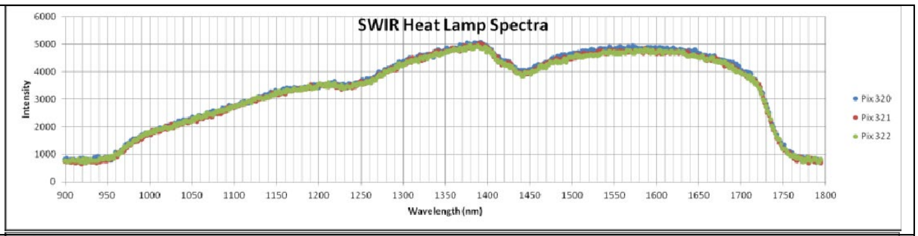


LED Strip Light
(only visible range)

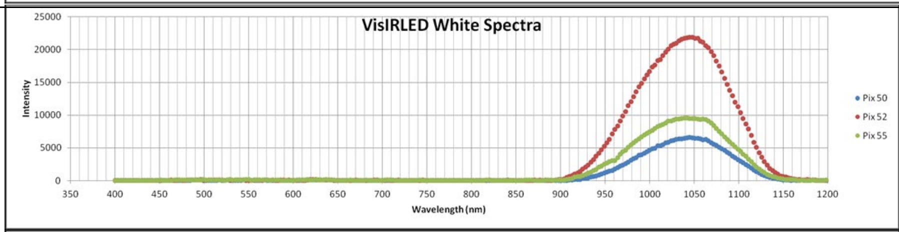


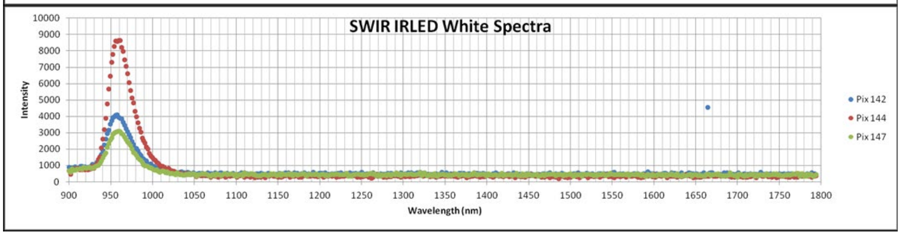
Heat Lamp



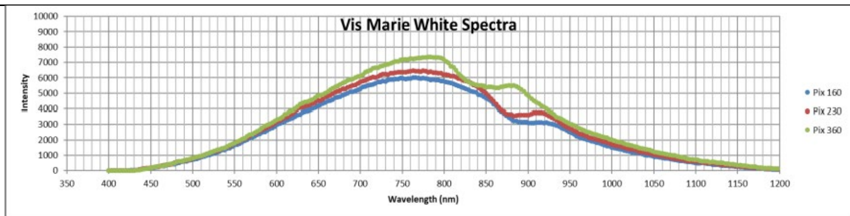


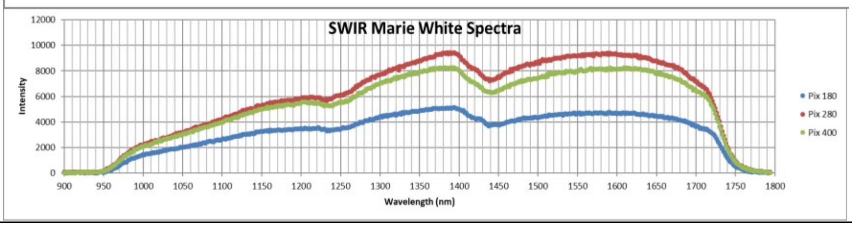
IR LED
(only IR range content)





QIR Heat lamp

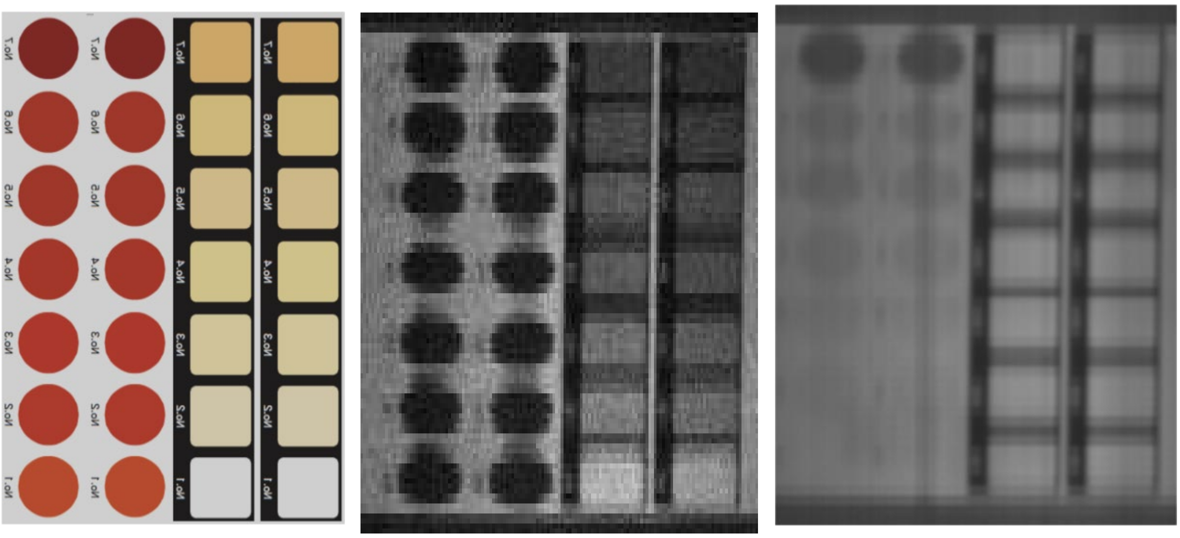




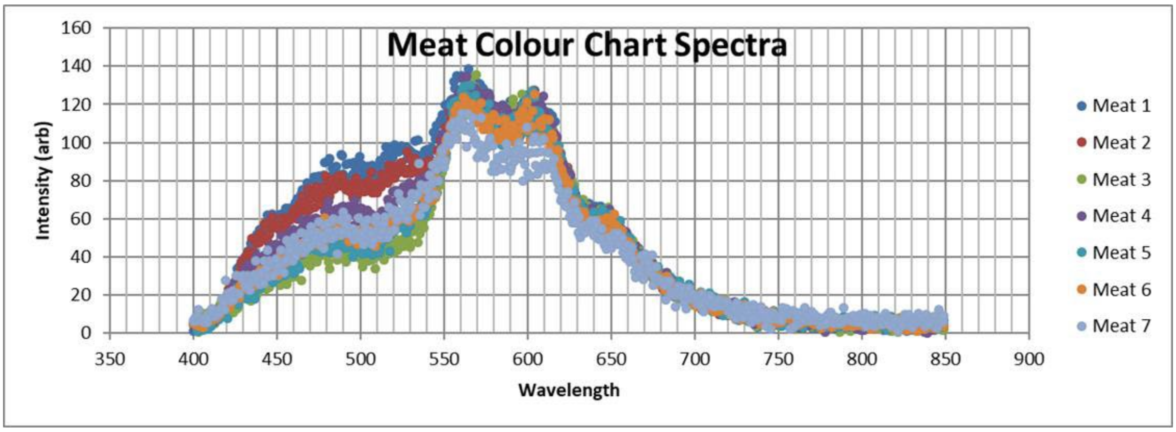
Range of light sources tested. The least noisy plots are the desirable highest brightness. We have been working with the QIR heat lamp, which provides both spectral range and high brightness. The QIR heat lamp is designed for food warming in Bain Maries and generate a lot of heat. We will monitor the implications, if any, of this.

2.1.5 Hyperspectral camera imaging – Meat Grading Test Pattern

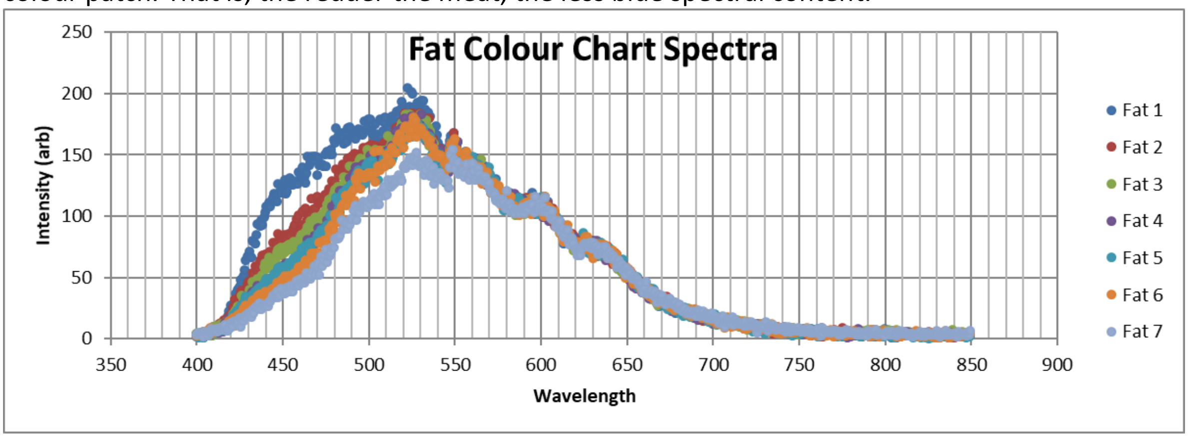
A meat-grading test pattern was imaged to measure the spectral content across the expected fat and lean (offal) content.



Meat test pattern imaged in a visible (middle) and an SWIR (right) wavelength band, each showing differenct contrast.



Lean (meat) colour content for each test chart colour measured with the visible camera. The differences between the colour tests appear in the amount of blue green (400-550nm) in each meat colour patch. That is, the redder the meat, the less blue spectral content.

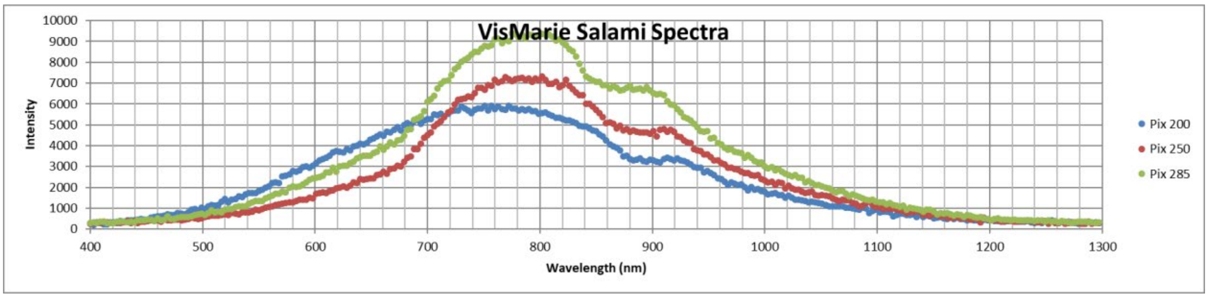


Similarly, for the fat colour patches, more blue means whiter fat.

2.1.6 Hyperspectral camera imaging - Salami

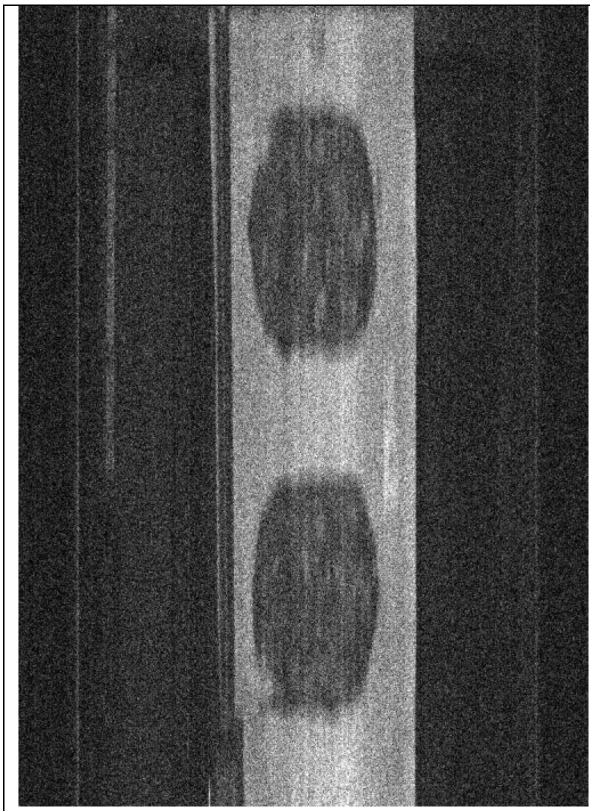
Sliced salami was chosen as a good example of mixed fat and lean (offal) content.

Two slices of salami on wax paper.

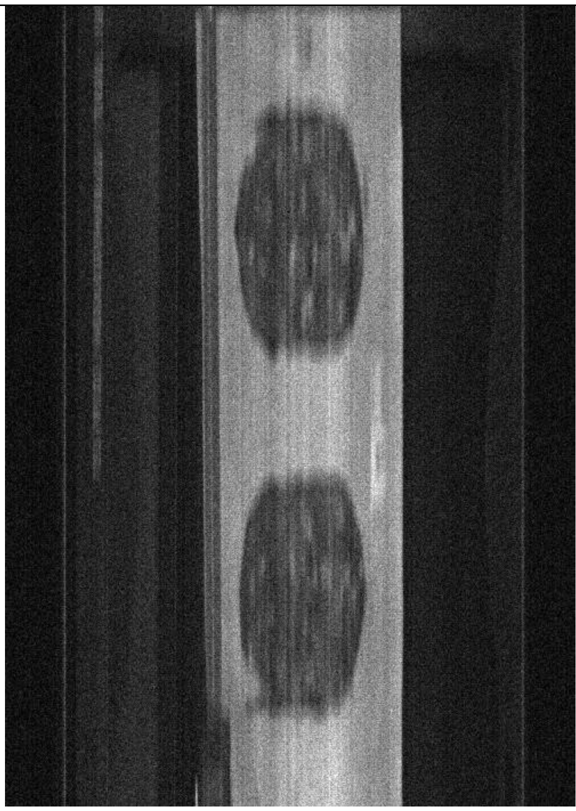


Spectral plots for both visible and SWIR spectral content. These plots are averages to show the overall difference salami to paper. Pix200 (blue) is an average for the wax paper and shows good (white) visible (400-700nm) content. Pix250 and 285 are different regions of the salami.

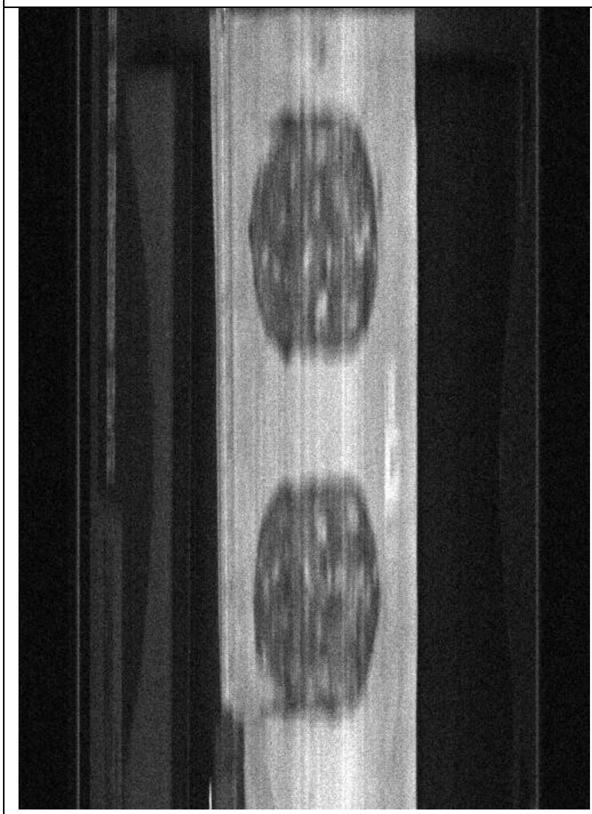
The following table shows a progression in wavelength images for the salami. You can see that at visible wavelengths the paper appears brighter than the salami. The contrast is then inverted at IR wavelength.



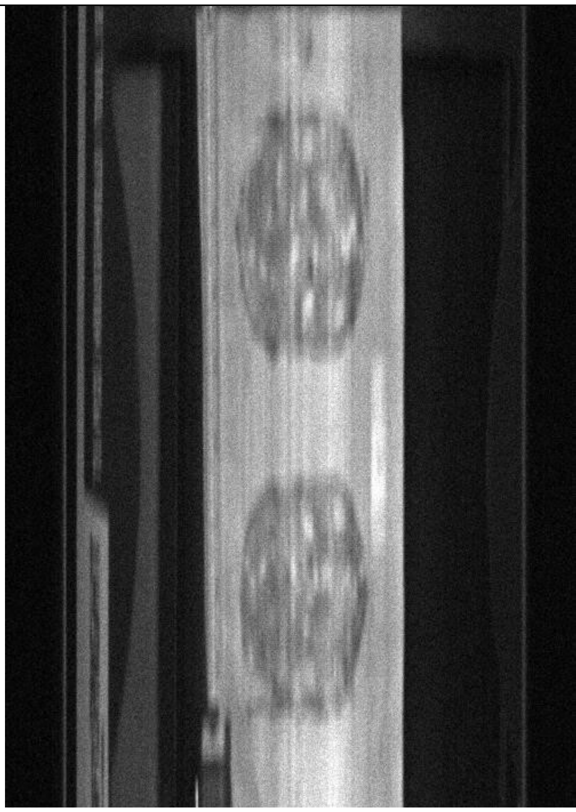
520nm



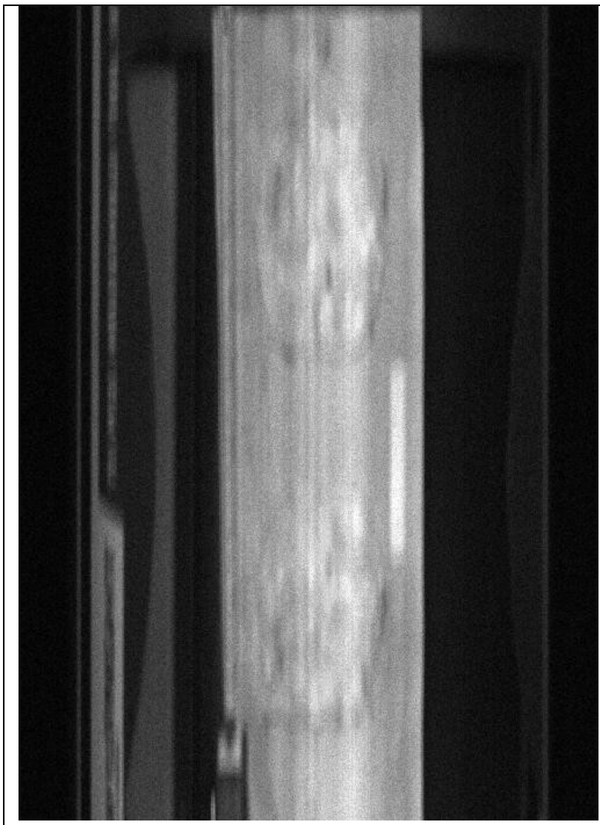
580nm

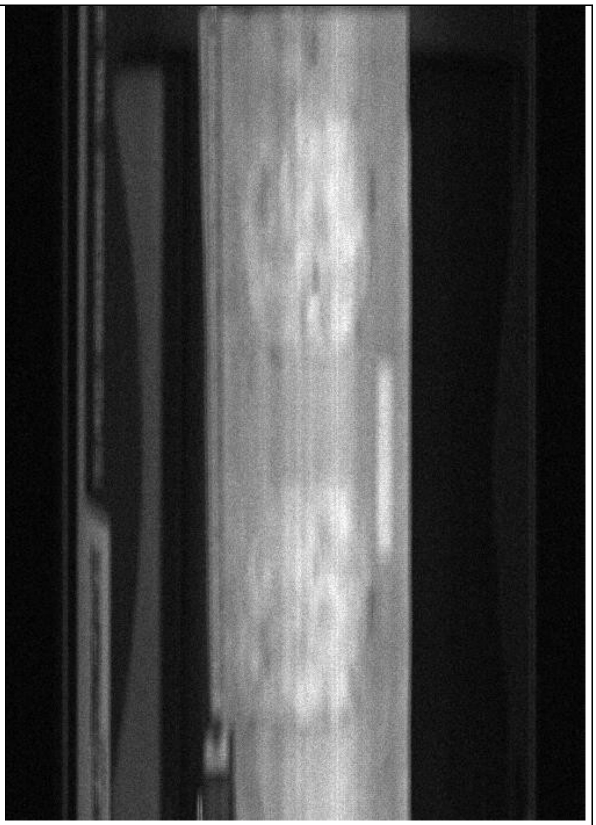


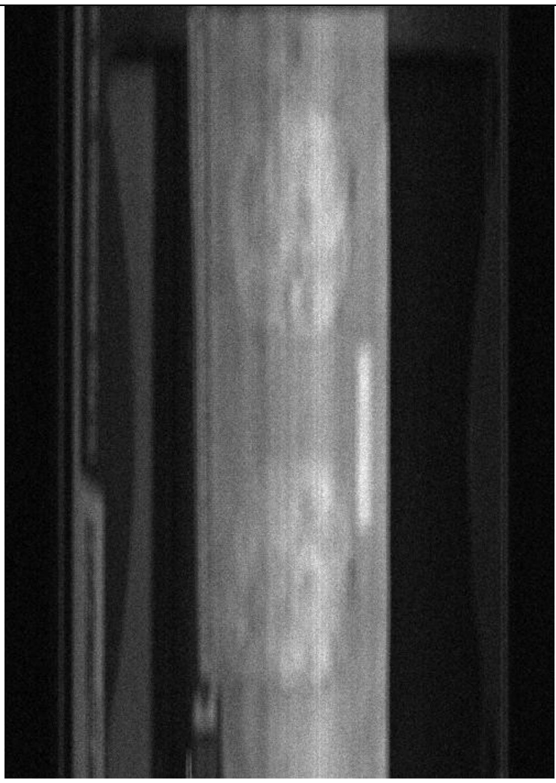
640nm

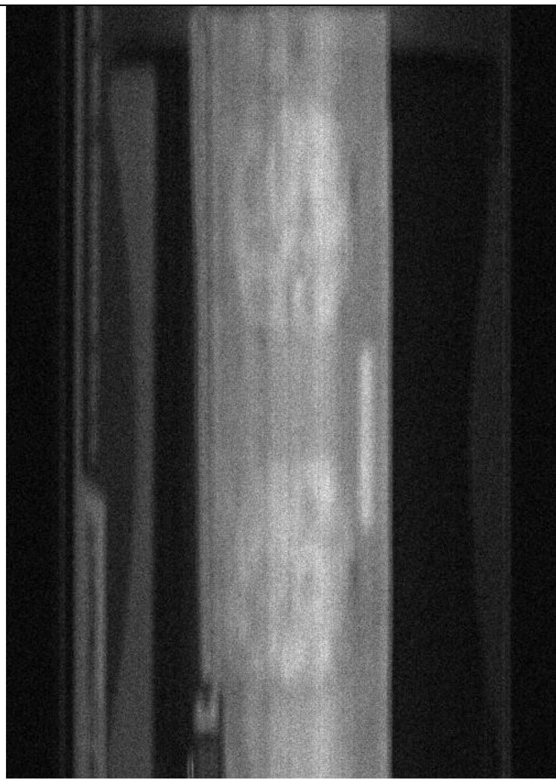


700nm


760nm

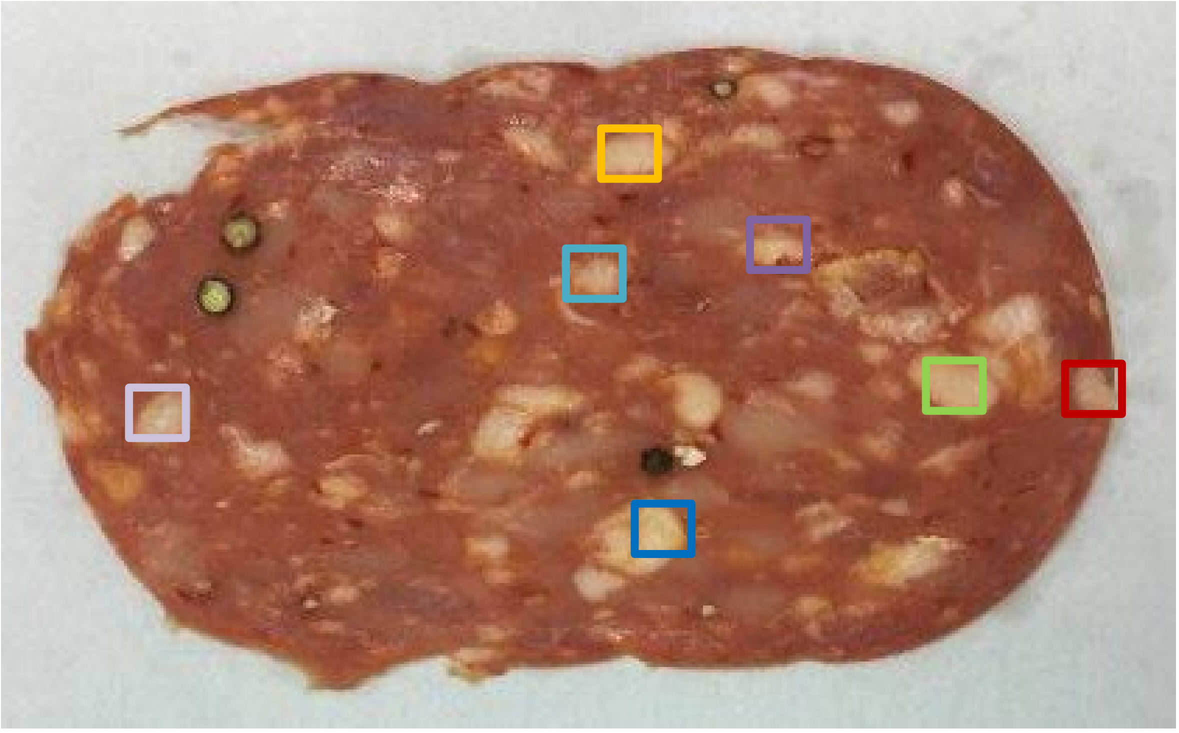

820nm

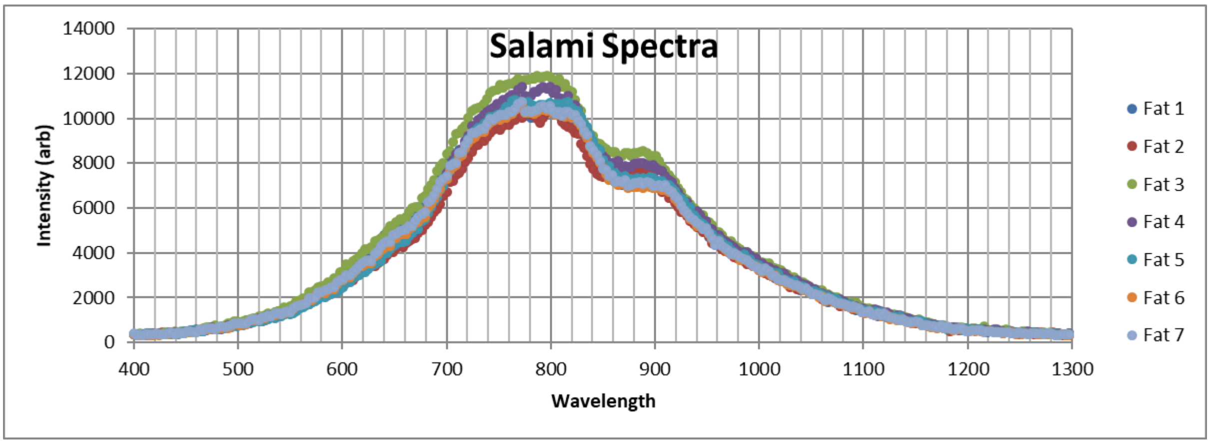

880nm


940nm

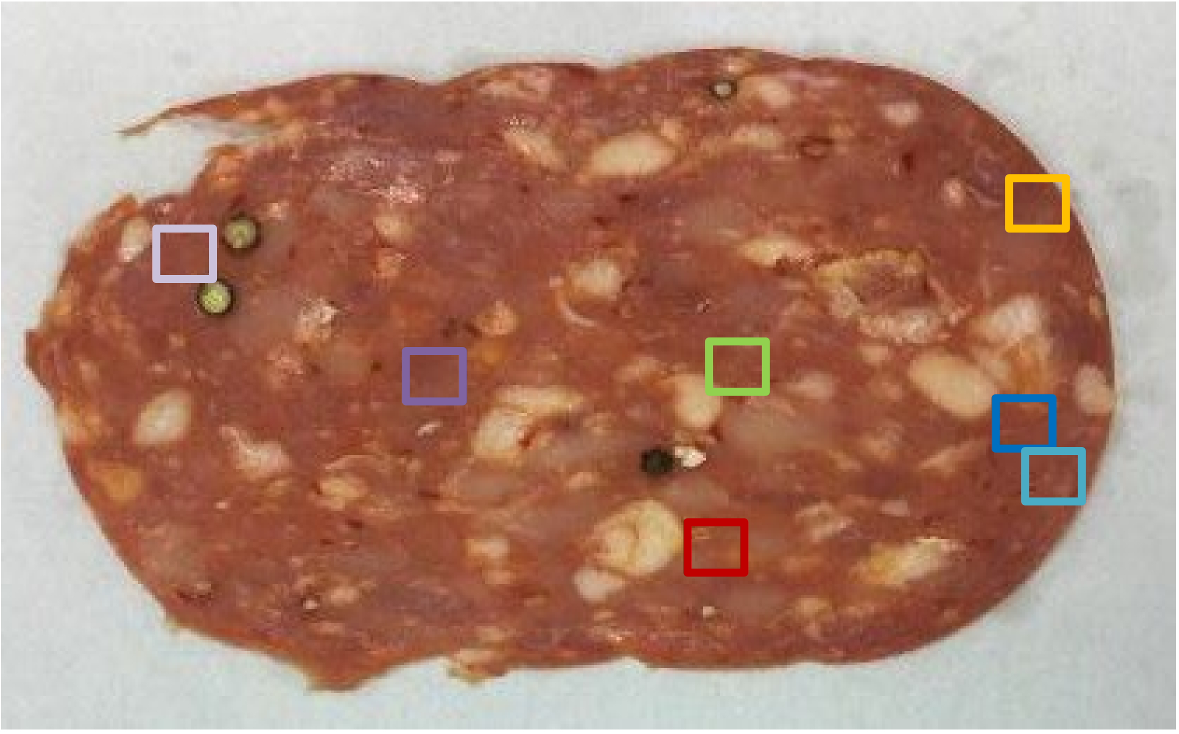
The following figures display features within the salami slice in terms of their spectral content. In these figures note:

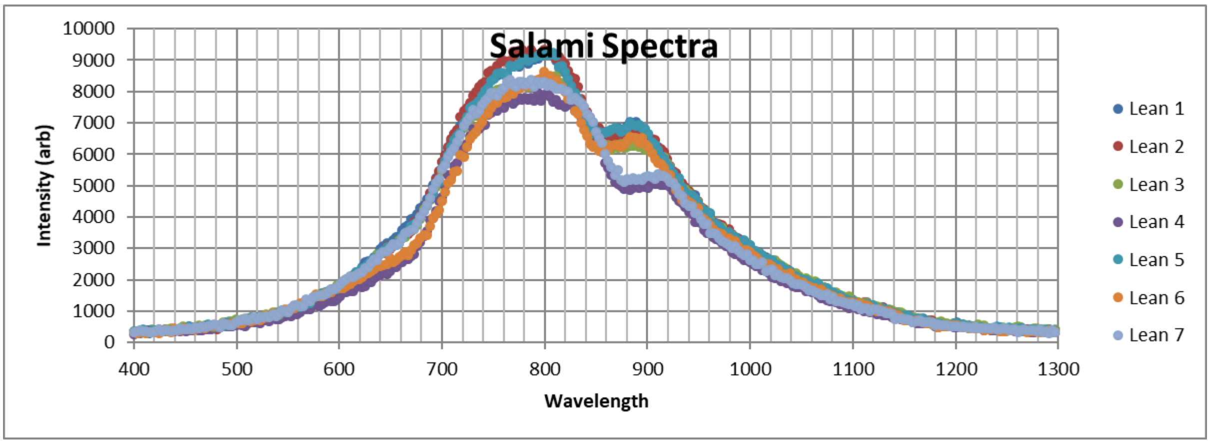
- The whiter fat regions in the first figure have higher values in the 500-600nm range, than in the lean plots (second figure) and the yellow fat regions (third figure).
- The range 840-920nm shows excellent variation, and therefore discrimination potential. Lean displays spectral differences in this region.



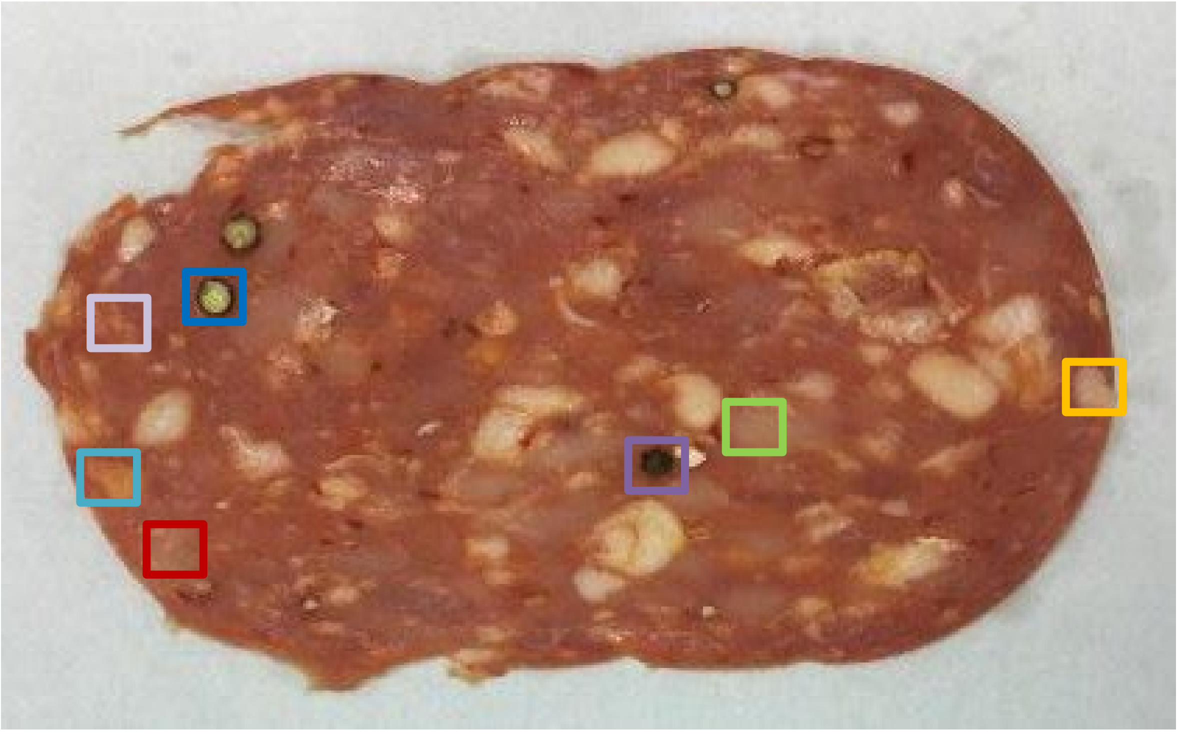


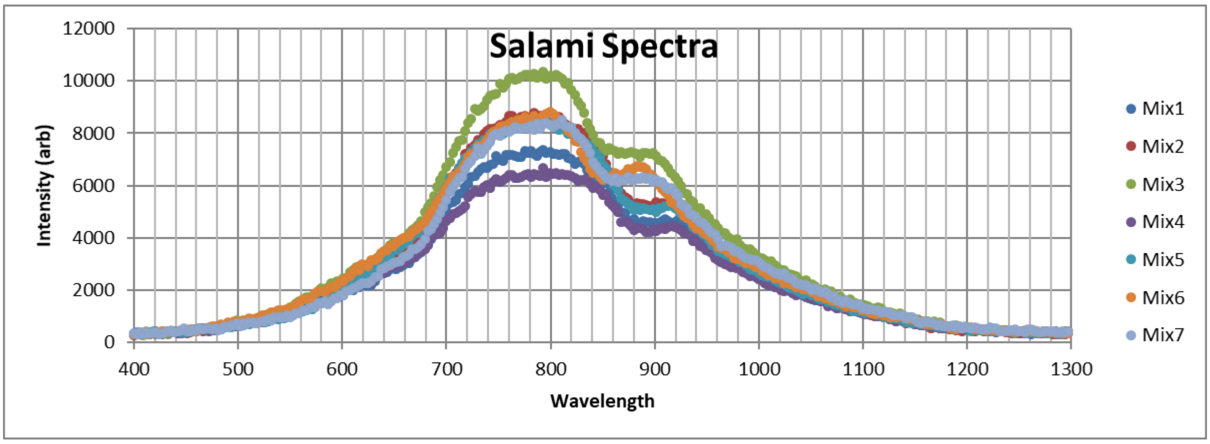
Colour-coded plots of the spectra for regions of fat. White fat spectral content is fairly uniform, but different from the less-white regions of the third figure (Mixed, below).





Colour-coded plots of the spectra for regions of lean. Clear spectral differences in regions 4 and 7 relative to the other lean regions.





Colour-coded plots of the spectra for regions of mixed content.

The observed differences in both the intensity and distribution of the spectral wavelengths confirm the utility of hyperspectral imaging for discriminating and identifying fat, lean and other content.

2.2 Software

2.2.1 Hyperspectral Camera Interface

Working closely with the hyperspectral camera suppliers, the hardware integration team has developed off-line protocols to interface, read, download, manipulate and process the camera image content in real time. Upon delivery, these protocols will drive the camera image acquisition.

Currently, we are processing the tridiagonal matrix-multiplication and transpose of 512x400 pixel images at 360fps on the DSPs of the system's FPGA data processing chip (Texas Instruments AM5728). In the future, we might need to do more computationally intensive Penta diagonal matrix multiplication. We envision this will be adequate performance.

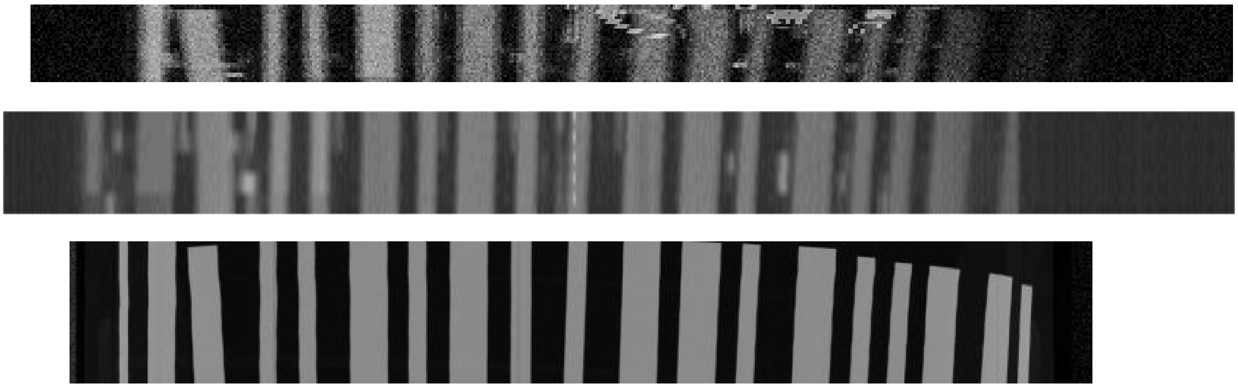
Accepting the camera data rate, we are getting about 100fps, or 400Mbps over the Gig Ethernet connection via the Aravis library. Aravis is a glib/object-based library for video acquisition using gigabit ethernet (and other data protocols). To get all the way to 200 fps will requires writing our own raw socket connections, to avoid the buffer reassembly that Aravis does. To achieve this, we believe will require Jumbo packets (MTU=9000) and IP bypass. Camera support of these latter modes is being confirmed.

Finally, the addition of X-ray image processing will follow the same techniques.

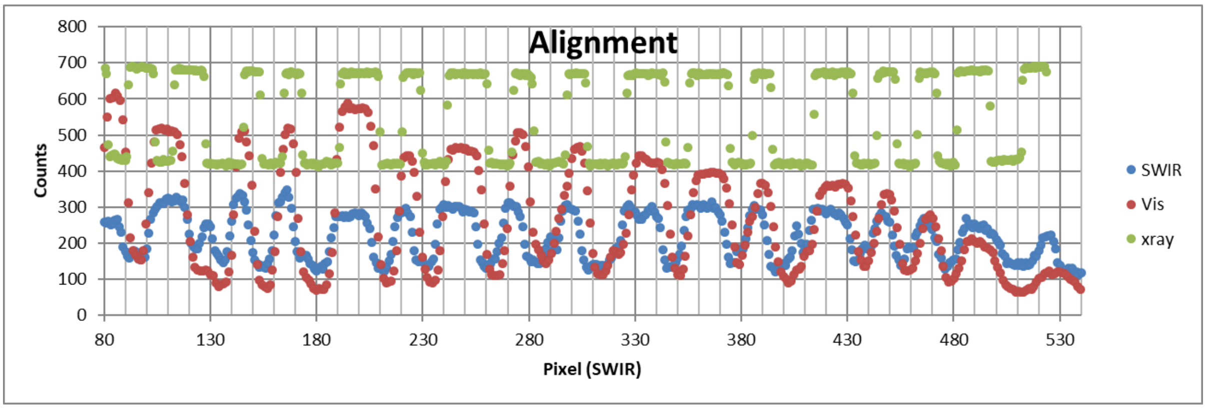
2.2.2 Image Fusion – Spatial

To properly analyse the three imaging modalities, x-ray, visible and SWIR, from the three different cameras, we need to align the image content both spatially (across the conveyor) and temporally (along the conveyor).

The spatial alignment can be performed once, e.g. at the factory for a given mounting of cameras and x-ray generator-detector geometry. An example of this alignment is shown below for a bar code test pattern image in each mode. Ideally, this alignment can be automated.



Images of a bar code in visible (top), SWIR (middle) and x-ray (bottom) used to scale, calibrate and align images captured by the three cameras.

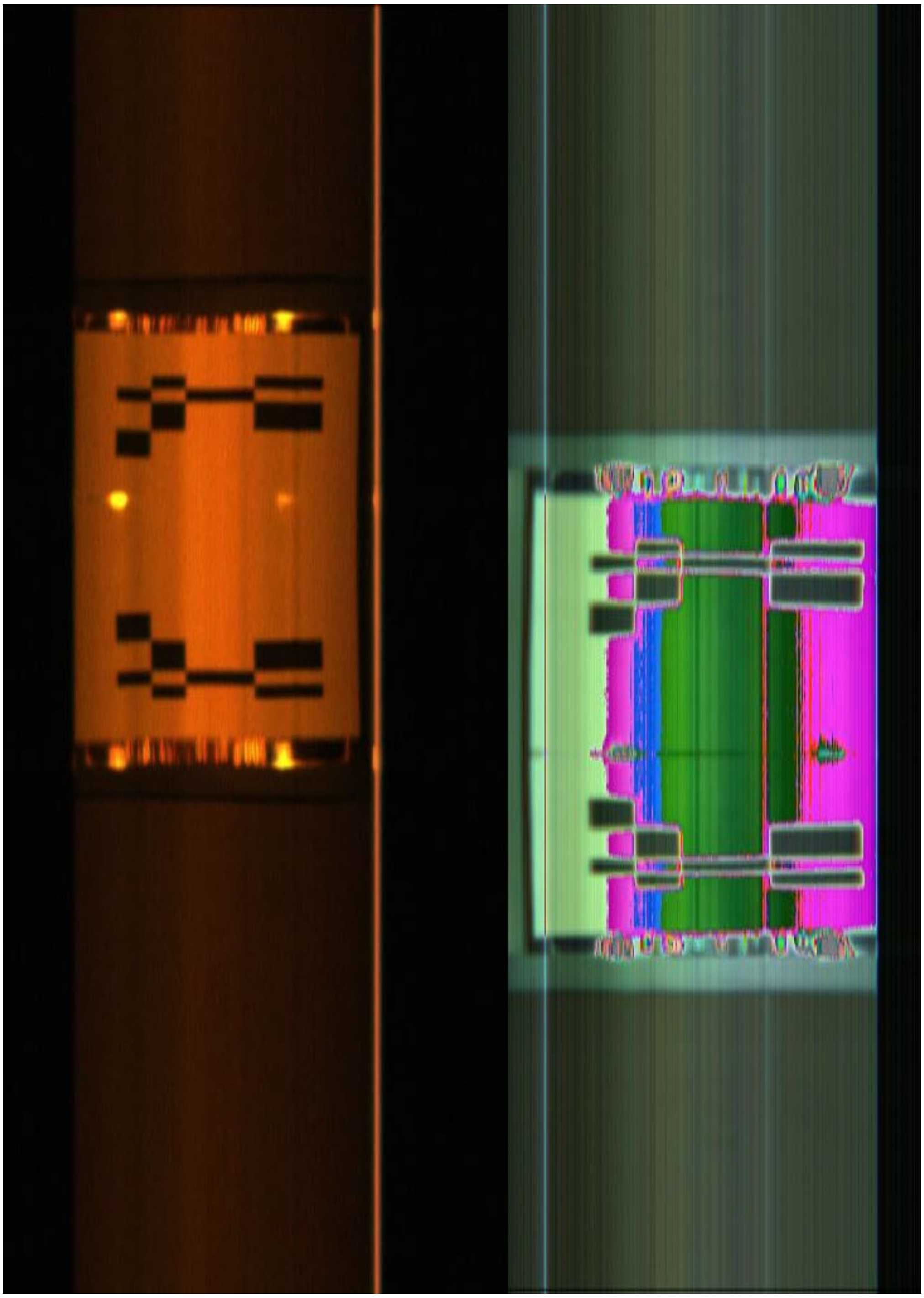


Equivalent line profiles through the bar codes for the three modalities, showing it to be bi-modal enough to automate this process.

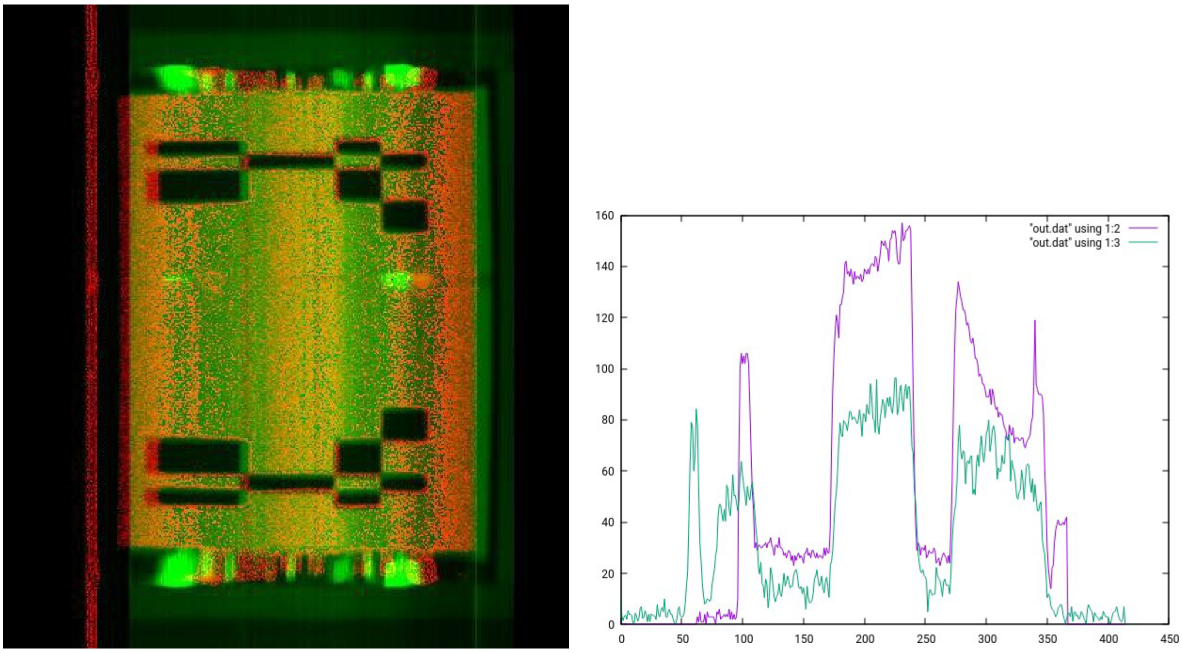
2.2.3 Image Fusion – Temporal

The temporal (along conveyor motion) alignment of the cameras is more difficult, as it needs to be performed for each scan. This requirement compensates both the frame capture rate of the individual cameras, and their individual starting delays.

An example of this process is shown below. A two-dimensional pattern is imaged by both cameras. The differences in the two images horizontal (spatial) and vertical (temporal) scaling is obvious.



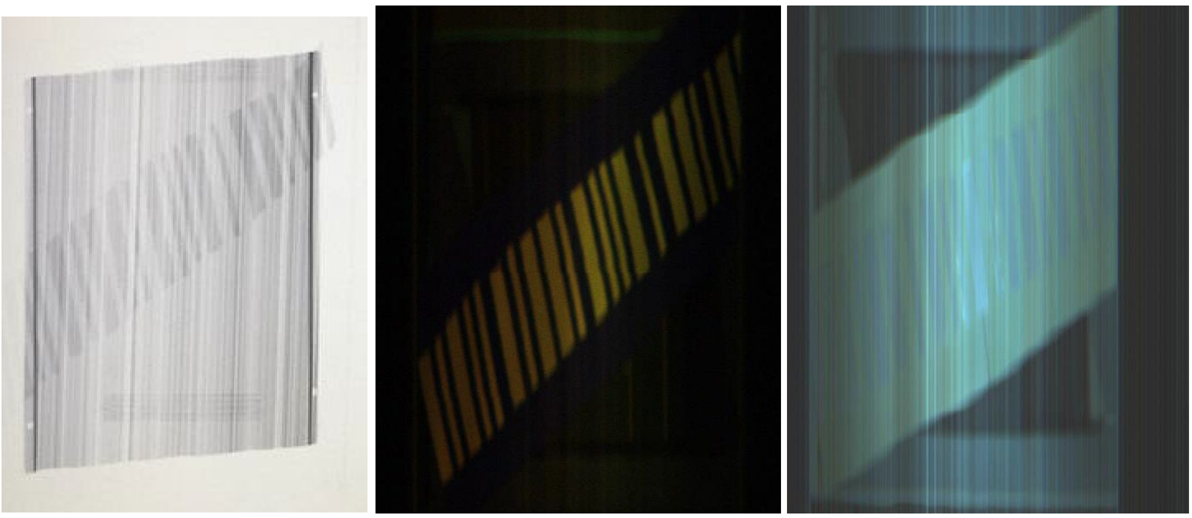
Images from the visible (left) and SWIR (right) hyperspectral cameras.



The final aligned test pattern images superimposed on each other (left) and the line profiles of the temporal alignment (right).

2.2.4 Simultaneous camera acquisition

Spatially, the camera resolutions are each about 1mm per pixel. This is fixed by camera sensor dimension. In the temporal direction (along the conveyor direction of motion), the resolution is frame rate dependent. Ideally, the cameras are capturing at 100 frames per second or better in scanner operating conditions. A conveyor speed of 200mm/sec, at 100fps gives 2mm resolution. Simultaneous camera captures at these frame rates require a lot of computer bandwidth. Below are simultaneous captures for the three cameras of a scanned bar code test piece. The test piece is placed at an angle so that any frame drops (bandwidth limitations) will be obvious as breaks in the continuity of the bar code. Clearly, there are few dropped frames.



X-ray (left), visible (middle) and SWIR (right) scans acquired simultaneously. Note, other distortions are a consequence of non-uniform roller motion.

3 Success in meeting the milestone

3.1 Milestone 3

3.1.1 Update

The following works have been completed:

- Install commercial hyperspectral imaging cameras and illumination into the tunnel of the 6040DV-ME x-ray scanner.
- Electromechanical integration of the two camera systems with the 6040DV-ME x-ray scanner.
- Develop software to integrate the two camera systems with the 6040DV-ME x-ray scanner.

The Rapiscan Systems 6040DV-ME x-ray scanner is now ready to be shipped to the University of Sydney (Camden Campus) to screen offals in order to:

- Develop image fusion and classification algorithms for the offal abnormalities and defects.
- Define histopathological abnormalities and defects in offals: type, location and size.
- Capture images of a range histopathological abnormalities and defects in offals from the multi-sensor system.

4 Conclusions / recommendations

4.1 Conclusion

4.1.1 General

Based on the work undertaken and results achieved during this phase of the project, it has been determined that a multi-sensor system, combined with hyperspectral and colour imaging cameras, should be able to identify defects and abnormalities during screening of red and green offals at speeds consistent with industry processing operations.