# Novel NIR interactance measurements for non-contact core temperature of processed meat products

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## Introduction

Core temperature is a critical control parameter in the monitoring of cooked, ready-to-eat products, in terms of yield loss, food safety and energy efficiency. Typical current practice involves random product sampling followed by thermocouple insertion into what is the part that takes the longest to cook, which incurs large batch losses if an incorrect temperature level is read. This error can easily be up to 60°C for complex products thus requiring that food is overcooked to ensure that everything is cooked. In the case of liver pâté, for example, trays are cooked to 90°C and in the case of "wiener" sausage manufacturing, the ideal temperature is generally around 76°C and the measurement of these temperatures can vary ±2°C. These temperatures are required due to the large exposed surface area during emulsification and mixing when making these products leading to higher probability of bacterial growth. The temperatures need to be monitored continuously to ensure the process runs correctly and due to the large throughput, large batches would need to be destroyed if there is an error. Much research in the area of non-contact core temperature measurements has involved developing complex models based on the surface temperature,[1] but in the research presented here, by incorporating online non-contact NIR interactance measurements (Figure 1), non-contact infrared core temperature measurement has been taken a step further by monitoring light that has travelled up to 2 cm into the product, thus enabling simpler core temperature models that are not so heavily dependent on surface temperatures and complex modelling of the heat transfer in the product.

This depth of penetration for each product is determined by placing the product on top of a highly reflective material firstly and then on a black absorbing material and gradually slicing layers off while recording the spectra. The point at which the spectra from these two set-ups deviate, is the depth to which the light penetrates.

## Materials and methods

Previous research[2] in the area of fat and pigment measurements in live salmon, resulted in the development of an NIR measurement system that eliminates surface reflection and resolves the interacted light into VIS and NIR spectra, each with a 20 nm resolution (460–740 nm and 760–1040 nm). During the core temperature investigation, the NIR region was used, with focus on the second overtone of water at 970 nm, which undergoes a shift to higher wavelengths with dec reasing temperature (note the slope difference between the two points in the peak in Figure 2).

Tests were performed on two Norwegian products; Gilde liver pâté and hot dogs ("wiener" sausages). Initial feasibility investigations were conducted on the hot dogs, while a more extensive study was carried out on the liver pâté.

Twenty-eight sausages were cooked to temperatures between 65°C and 83°C, with corresponding NIR measurements taken from each sausage. The sausages were also cooled and temperature and NIR measurements were taken between 1.8°C and 9.2°C.

Thirty containers of pâté, 4cm high, were brought to an initial equalised temperature of 40°C as done in industry. They were then baked to temperatures between 71°C and 101°C. The temperature half-way down (core) was recorded with a K2 type thermocouple at two different positions on the pâté; centre and halfway between the centre and edge as one looks down on the pâté. Rapid (1 s) NIR measurements were then taken at these two positions. The trays of pâté were also cooled and temperature and NIR measurements were taken in the range 3.1–22.6°C.

Partial least squares regression (PLSR) was performed on the data, after both the inverse logarithm and standard normal variate (SNV) were applied to the data, to obtain calibration models for heating and cooling, using the core temperature readings. Calibration development was done with the software package, Unscrambler 9.7 (Camo Software AS, Oslo, Norway).

A test set of 30 more containers of pâté, from a different batch, was baked to test the heating model for the pâté. The test set was divided into two groups; 1) samples with an initial temperature

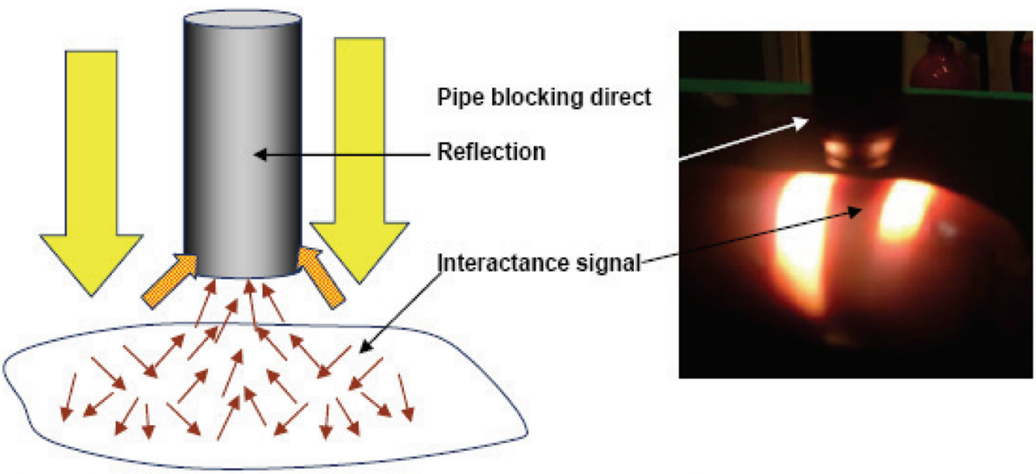


**Figure 1.** Non-contact interactance in hot dogs. Samples are presented just below pipe.

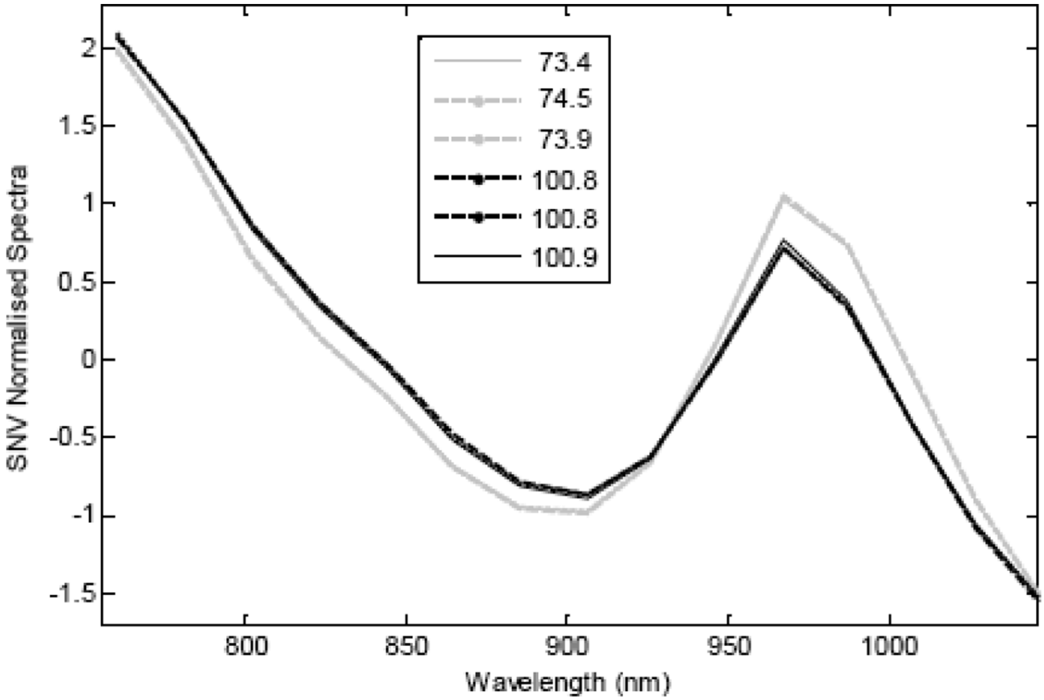


**Figure 2.** Sample SNV corrected spectra from pâté at various temperatures.

of 40°C that were cooked at a faster rate creating a darker crust with different scattering properties and 2) samples that were cooked the same way as the calibration set but with three different initial core temperatures, 3°C, 13°C and 40°C, to achieve an exaggerated temperature variation in the product. Though this temperature variation would not be found in a realistic processing

**Table 1. Calibration results for hot dog and pâté models.**

| Model | Heated hot dog | Chilled hot dog | Heated pâté | Chilled pâté |
|---|---|---|---|---|
| Temperature range | 65–83°C | 1.8–9.2°C | 71–101°C | 3.1–22.6°C |
| No. of PCs | 2 | 2 | 2 | 3 |
| $R^2$ | 0.927 | 0.875 | 0.951 | 0.972 |
| *RMSECV* /% | 1.57 | 0.933 | 1.74 | 0.99 |
| *Bias* | 0.027 | –0.01 | 0.012 | 0.008 |

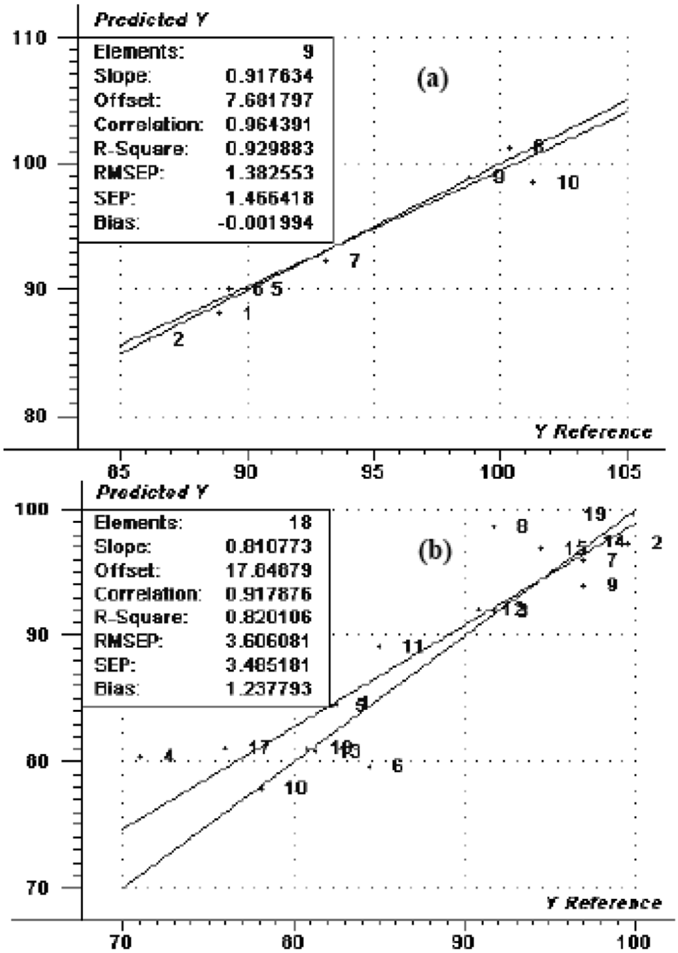


**Figure 3.** Prediction of test sets 1 and 2, which contain samples with a) darker crust and b) exaggerated temperature variation within the pâté.

plant, it gives a good indication of the robustness of the model and how deep in to the product the temperature was actually measured.

## Results

PLS models were generated for heated and chilled hot dogs in the feasibility test, and for heated and chilled pâté in the study. Cross validation was applied to evaluate each model's predictive ability. The prediction error, which was estimated by the root mean square error of the cross validation (*RMSECV*), was 1.57°C for the heated hot dogs (range 65–83°C), 1.39°C for the chilled hot dogs (range 1.8–9.2°C), 1.74°C for the heated pâté (range 71–101°C) and 0.99°C for the chilled pâté (range 3.1–22.6°C) (Table 1).

To validate the performance of the heated pâté model, it was used to classify the two test sets. The root mean square of the prediction (*RMSEP*) was 1.38°C and 3.3°C for test set 1 and 2, respectively (Figure 3).

A *RMSEP* of 1.38°C for test set 1 is encouraging as it is well within the range of human error when the measurement is taken randomly and manually. The higher error for test set 2 is still within the human error range but is too high when compared to the accuracy of a thermocouple. It is, however, expected, as the light travels from the surface to 2 cm down, and the variation in the temperature profile of this test set was exaggerated to produce enough variation in the product to test the model's robustness. To understand the reduction in performance it is necessary to take into account the relative temperature profiles of the two test sets, which would be very different from each other as they were cooked at different speeds and had different starting temperatures. An advantage of this outcome is that because the light contains information, not only from the core, but from the surface down to the core, the system could potentially monitor the cooking development of the pâtés. Future work will involve expanding the model to provide information regarding the temperature profiling, e.g. surface temperature, core temperature and the temperature between the core and surface, to allow more detailed profiling of the cooking process in terms of how fast the outer layer is cooking compared to the core so that even cooking is obtained.

## Conclusion

Encouraging results have been obtained in predicting core temperatures of sausages and pâté, both cooked and chilled, with an *RMSECV* of less than 1.75°C obtained for all models. The results also show the potential of the system to predict temperature profiles in first 2 cm of the product, which would be beneficial in monitoring the cooking profile within the oven.

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