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Comparison of various wavelet texture features to predict beef palatability

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ABSTRACT

The wavelet transform can be used to characterise the surface texture of beef images in a more efficient manner than classical algorithms such as co-occurrence and run lengths. Features extracted from wavelet decompositions have been used to develop predictive models of important palatability attributes. A variety of common wavelet transforms were considered (biorthogonal, reverse biorthogonal, discrete Meyer, Daubechie, symmetric modified Daubechie and Coifman modified Daubechie) to search for the most useful texture features. A classic run length and co-occurrence algorithm was used for comparison. Using the same data analysis methods for each wavelet type, predictive models of beef acceptability, tenderness, juiciness, flavour and hardness were developed. Genetic algorithms succeeded in finding more accurate models than stepwise and manual elimination except for hardness. An accurate model of flavour ($r^2 = 0.84$) was computed. A good model of overall acceptability ($r^2 = 0.79$) was computed that fell just short of an important benchmark of accuracy. An encouraging model of juiciness ($r^2 = 0.71$) was computed showing that with additional palatability information juiciness might be accurately modelled. Tenderness proved difficult to model with only the classic model satisfying stability criteria and a poorer result ($r^2 = 0.64$) meaning substantial additional palatability information is required for accurate modelling. Hardness was particularly difficult to model. The biorthogonal wavelet produced the best model for three palatability measurements but the symmetric modified Daubechie wavelet produced the best model of overall acceptability and thus must be viewed as the most useful wavelet type.

1. Introduction

Beef is a high value meat due to its expected palatability. It is a popular foodstuff and is consumed on a large scale worldwide (USDA, 2006). The beef *longissimus dorsi* or "steak" is particularly valuable due to its superior palatability (USDA, 2008). Thus accurate quality classification of beef at an early stage of processing is essential to ensure correct market distribution. A comprehensive approach to model beef palatability was undertaken by Meat Standards Australia (MSA). This is described in detail by Watson, Polkinghorne, and Thompson (2008). Such a comprehensive approach is very demanding in terms of finance, personnel, expertise and time.

A more practical approach is to develop a relationship between measured palatability and measurable raw beef characteristics such as those listed by the United States Department of Agriculture (USDA, 1997) and then use the relationship to predict the palatability of future carcasses. This approach has an essential benefit in that it uses indicators that are influenced by carcass pre- and post-slaughter treatments and can thus be expected to be strongly representative of palatability. Thus vitally important carcass treatment parameters that would impact on palatability such as carcass chilling conditions are reflected in the indicators. The importance of carcass chilling conditions is discussed by Jackman, Sun, Du, Allen, and Downey (2008) and Jackman, Sun, Du, and Allen (2009). Other important factors such as the addition of growth promoting hormones (HGP) would also be reflected in the indicators. Use of HGPs increases the volume of beef muscle but can have a detrimental effect on palatability (Thompson et al., 2008). HGPs are illegal in many countries including Ireland and most European countries. Some important process parameters such as aging time which is an important factor in the development of desirable palatability characteristics such as tenderness, juiciness and flavour (Laster et al., 2008) will not be reflected in the palatability indicators as measurement takes place 2 days after slaughter. Despite this the measurement at 2 days post-slaughter is still representative of the expected palatability after further aging. An aging time of 14 days (including the 2 days post-slaughter) would be typical for Irish beef processing.

Ideally palatability would be measured by a consumer panel as ultimately the customer must be satisfied. This is however an ambitious task and is usually impractical due to time and financial considerations. More practical means of assessing palatability are trained sensory panels and Instron testing, in particular the Warner Bratzler shear force (WBSF). Both sensory panels and WBSF

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are commonly used in assessing beef tenderness (Daniel, Dikeman, Arnett, & Hunt, 2009; Jackman et al., 2008, 2009).

Expert graders can measure the raw beef characteristics such as those listed by the USDA (1997) and make a prediction of the palatability based on their training and experience. However this suffers from inherent problems of subjectivity and inconsistency (Sun & Brosnan, 2003) as well as being relatively expensive. Thus what is required is a means of making objective, consistent, rapid and low cost measurements of the raw beef characteristics. With such data it would be possible to use chemometric tools to train and test models linking measured raw beef characteristics with measured palatability. These models can then allow the palatability of future carcasses to be predicted based on their measured raw characteristics. Thus replacing the expert grader. Chemometric tools such as partial least squares regression (PLSR) have been shown to be highly suitable for attempting to modelling variability in the palatability of beef (Arvanitoyannis & Van-Houwelingen-Koukaliaroglou, 2003; Jackman et al., 2008; Jackman et al., 2009; Li, Tan, Martz, & Heymann, 1999; Tian, McCall, Dripps, Yu, & Gong, 2005) and can yield the required quantifiable models relating appropriate raw characteristics to palatability.

The means of acquiring the required objective and consistent data is computer vision. A computer vision system acquires high resolution digital images of a food product under consistent illumination conditions. With suitable image data processing it will yield objective and consistent food features suitable for use in chemometric modelling of palatability or other quality parameters. Computer vision has had numerous successful applications in food technology (Sun, 2008) and has been successfully applied to the analysis of meat (Aguilera & Briones, 2005; Du & Sun, 2004). Tan (2004) identified computer vision as the most promising means of objectively assessing meat quality from its fresh characteristics. Computer vision can thus offers a means of objective, consistent and speedy analysis of the USDA raw beef characteristics (USDA, 1997).

Surface texture is a very important palatability indicator in the USDA system (USDA, 1997) and plays a large role in the overall palatability judgement. Much previous research has shown that computer vision analysis of raw meat surface texture contains at least some useful information on cooked meat palatability and this information can substantially contribute to a predictive model (Chandraratne, Samarasinghe, Kulasiri, & Bickerstaffe, 2006; Jackman et al., 2008; Jackman et al., 2009; Li et al., 1999; Tian et al., 2005). Crucially computer vision systems can analyse texture in ways that cannot be perceived by the human eye, allowing for more powerful and efficient texture analysis.

To evaluate surface texture features the original image must be converted to a grey scale. Research on similar experimental samples by Li, Tan, and Shatadal (2001) indicated that the saturation channel is the most useful grey scale. This comes from converting the image from its original red, green and blue (RGB) colour space into the hue, saturation and intensity (HSI) colour space and using the second channel. The usefulness of the saturation channel is immediately obvious by observation. The value of each pixel relative to its neighbours indicates the texture of the image.

The bulk of previous research has opted to express meat surface texture with classical algorithms such as co-occurrence, difference histograms and run lengths (Chandraratne et al., 2006; Li et al., 1999; Tian et al., 2005). While these are perceptions of texture that immediately make sense and can be easily understood by observation of an image, research by Jackman et al. (2008) and Huang et al. (1997) showed that the wavelet transform is a better means of characterising surface texture than classical algorithms. A discussion of the utility of wavelet based approaches in agriculture and food quality inspection is given by Singh, Choudhary, Jayas, and Paliwal (in press). The mathematical foundations of wavelets are given by Kaiser (1994). The Federal Bureau of Investigation in the USA applies the wavelet transform to compress fingerprint images without notable loss of fingerprint quality. This is explained in more detail by Wickerhauser (1994).

Computing a wavelet decomposition of an image involves some important choices: the type of wavelet or wavelet "family" to be used, the number of orders of the wavelet to be applied and the level of decomposition to be performed. Wavelet families fall into five groups, .i.e., crude wavelets, biorthogonal and compactly supported wavelet pairs, orthogonal and compactly supported wavelets, complex wavelets, and finally infinitely regular wavelets. Each has a number of advantages and disadvantages for analysing a particular problem. As indicated by the Matlab user guide (The Mathworks, 2004), both the biorthogonal and compactly supported wavelet pairs (biorthogonal (bio) and reverse biorthogonal (rbio)) and the orthogonal and compactly supported wavelets (Daubechie (daub), symmetric modified Daubechie (sym), and Coifman modified Daubechie (coif)) are suited to discrete transform with the fast wavelet transform algorithm. Infinitely regular wavelets can be modified to make them suitable for discrete transform with FIR filters but without the fast algorithm, resulting in the discrete approximation of Meyer (dmey) wavelet. This is important as the Matlab programming used only supports FIR filters. Each wavelet family has a number of typical orders ranging from a single order for the dmey wavelet to fifteen for bio and rbio. The level of decomposition is limited by image size. Discrete transforms need images of size 2^k (dyadic) for efficiency; the possible level of decomposition is equal to k. Hence each chosen decomposition level for each chosen wavelet order for the chosen wavelet family yields a horizontal, vertical and diagonal detail coefficient as well as an approximation coefficient. In addition to these the raw non-decomposed image has an approximation coefficient. Thus there are $4k + 1$ possible coefficients for each wavelet order for the chosen wavelet family. The resulting horizontal, vertical, diagonal and approximation coefficients can be used to simulate the image quite accurately with at most a few hundred parameters via the inverse transform. As images for use in wavelet applications might be 256×256 or even 512×512 in size this is a reduction to below one percent of the original number of variables.

Previous research by Jackman et al. (2008) found the sym wavelet to be the most useful wavelet family for providing useful surface texture features. This assessment was made only on the basis of modelling overall acceptability. A wide range of palatability measurements were subsequently included for modelling in that research once the sym wavelet was chosen. As the sym wavelet may not be the most useful wavelet family for modelling all palatability measurements, other common wavelet families should be reconsidered when searching for the best predictive models of palatability measurements other than acceptability. Combining results for all palatability measurements may lead to a reassessment of which wavelet family is most useful for characterising the surface texture of beef images.

Therefore the objectives of the current study are to develop accurate predictive models of a selection of important palatability measurements using surface texture features derived from a wide range of wavelet analyses. Using the results of these models the family of wavelet best suited to developing useful surface texture features of beef can then be identified. The best wavelet family can then be used in further research.

2. Materials and methods

2.1. Sample preparation

The same samples used by Jackman et al. (2008) were employed in the current study. These samples were taken from a pilot scale