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An embedded system based on DSP platform and PCA-SVM algorithms for rapid beef meat freshness prediction and identification

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ABSTRACT

Statistical and artificial intelligence learning algorithms such as Principal Component Analysis (PCA) and Support Vector Machine (SVM) are widely used in many meat quality assessment applications to classify and predict the freshness of beef meat. This paper presents the implementation of the PCA and SVM algorithms on an embedded system based on a Digital Signal Processor (DSP). A dataset of eighty-one hue, saturation, and intensity (HSI) beef meat images was used. The PCA is used as a projection and prediction model where the SVM is used for the classification and identification of the beef meat. Results obtained from PCA projection model on a desktop system using Matlab software show the projection of three groups which represent the degree of beef meat freshness during the days of cold storage. A perfect prediction of the new unknown samples was obtained by PCA prediction model. A successful rate 100% of classification and identification was obtained by SVM. The PCA and SVM methods were implemented on the C6678 multi-core DSP. The implementation results of these algorithms were similar as those obtained by Matlab software. The processing time of the algorithms measured on the embedded system was lower compared to the desktop system. The embedded platforms based on DSP as portable tools can be used to predict or identify the sample beef meat freshness anywhere and in real-time.

1. Introduction

During the past few years, we have witnessed the explosion in interest and progress in the development of robust techniques in food industry especially for high added value foods such as meat. Beef meat is a popular foodstuff and it is consumed on a large scale over the world (Kamruzzaman et al., 2015). It is an important constituent of the human diet and greatly prized by the consumers because of its high nutritional values (Peng et al., 2011).

Quality is a key factor for modern food industry because the high quality of product is the basis for success in today's highly competitive markets (Du and Da-Wen, 2005). The globalization of meat commerce and the logistics of distribution from processing centers make it difficult to maintain and ensure meat freshness. Thus, the meat processing industry is always searching for efficient and rapid technologies for assessment of meat quality and its freshness in order to satisfy the consumer's demands (Zhenjie et al., 2014).

Recently, automatic inspection system mainly based on camera and computer technology has been investigated for the quality assessment of meat products. This system known as computer vision has proven to be efficient and successful for online objective measurement of various meat qualities attributes (Peng et al., 2011). The first step in computer vision technology is the illumination and image acquisition systems, interested readers are addressed to (Jackman et al., 2011). Once data acquisition has been completed, and variables have been calculated, generally some form of dimensionality reduction is very important and needed because it allows collecting less data and generates a simpler model which is easier to interpret by the final user. Finally, a predictive model can be created to predict the class or the value of meat quality for any future samples.

Statistical and artificial intelligence learning techniques are the core of computer vision technology as it permit to build and predict appropriate models to each application. Partial Least Squares Regression (PLSR), PCA, Linear Discriminate Analysis (LDA), Multiple Linear Regression (MLR), SVM, neural networks and fuzzy logic, coupled with computer vision technology have been widely applied to classify and

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predict meat quality attributes (Borràs et al., 2015). (Sun et al., 2011) have compared the performance of computer vision coupled with MLR and SVM to predict beef freshness, results show that SVM gives the best performance percentage of 94.07%. (Jackman et al., 2009) have used MLR, LDA, and PLSR to predict beef eating qualities from color, marbling and texture, a high rate of correct classification was obtained (90%). (EL Barbri et al. 2014) have explored the fuzzy ARTmap artificial neural network to classify beef meat according to its degree of spoilage. A good classification rate was obtained (95.24%).

Most of these algorithms are generally developed and implemented on desktop computers which allow: rapid development, debug and test (Du and Da-Wen, 2005). However, as the image and the data set sizes increase, the algorithms become more complex, consequently the processing speed will be slower and cannot satisfy the requirement of real-time systems (Zhenjie et al., 2014). Moreover the detection system is bulky and hard to transport, therefore, there is a need to use other software processing platforms, portable and specialized on processing of large amount of data in real-time (Zhou and Peng, 2014). In addition, the optimization of the existing processing algorithms and the development of novel ones suitable for microprocessors are highly required in order to permit the material miniaturization and the real time assessment of meat quality (Xiao et al., 2014).

The objective of this paper was to implement in real-time classification and prediction algorithms in an embedded platform. This will permit to the detection system to be portable and miniaturized. We have chosen to implement PCA and SVM algorithms, which are widely used in many meat quality assessment applications, to classify and predict the freshness of beef meat. We have chosen the multi-core C6678 DSP form Texas Instruments (TI), as an embedded system processing unit, for its low power consumption, and high-performance fixed/floating point calculations. It has been used recently by many research communities to build high-performance and low power real-time signal processing systems (Texas Instruments, 2012)

The remainder of this paper is organized as follows. Section 2 will provide details of the material and methods. Section 3 represents the PCA and SVM algorithms. The implementation results and the computation times of the embedded and the desktop platforms are presented in Section 4. Finally, a conclusion is provided in Section 5.

2. Material and methods

2.1. Meat samples preparation

Beef meat samples were purchased from different providers from the market of the city of Beni Mellal (Morocco). The samples were transported under refrigeration to the laboratory. They were placed in plastic boxes and kept under cold storage at 4 ± 1 °C for nine days. The choice of 4 ± 1 °C temperature storage refers to the temperature storage of meat in grocery stores (Arsalane et al., 2017).

2.2. Embedded system description

The DSP is a processor developed for real-time digital signal processing. It can perform intensive numerical computations at high computing performances, such as performing multiple instructions per cycle (Arsalane et al., 2016; Klilou et al., 2014). The multi-core C6678 DSP provided by Texas Instrument (TI) is a low power and a high-performance fixed/ floating point DSP based on TI's keystone multi-core architecture. It integrates eight C66x DSP cores. Each C66x DSP core can run up to 1.25 GHz. The C66x DSP core is based on a Very Long Instruction Word (VLIW) architecture. The instruction set also includes Single Instruction Multiple Data (SIMD) operating up to 128-bit vectors. In the experimental platform, each core run at 1 GHz and dissipates 10 W of power. With eight cores running at 1 GHz, the C6678 DSP has a peak performance of about 128 single precision GFLOPS (12.8 GFLOPS/ watt).

There are three levels of on-chip memory. Each core has a 32-KB of Level 1 for Program (L1P) and 32-KB of Level 1 for Data (L1D). The level 1 is the nearest, and it is usually used as cache memory. Besides, each core has a local level 2 memory; it is slower than level 1, and its size is 512 KB. The level 3 or Multi-core Shared Memory (MSM) is shared and is concurrently accessed by eight cores; its size is 4 MB. In addition to that, up to 8-Gbyte external DDR3 RAM can be accessed by the C6678 DSP through a 64-bits bus. The evaluation module EVMC6678 contains 512 Mbytes of DDR3 RAM ((Texas Instruments,).

The EVM6678 evaluation module used is a standalone development platform. It has a single-wide equivalent connectors PICMG® AMC.0 R2.0 Advanced MC module (Xue et al., 2011). It contains one TI multi-core C6678 DSP, 512 Mbytes of DDR3-1333 memory, 64 Mbytes of NAND flash, and 16 MB SPI NOR flash.

The C6678 DSP contains several communications peripherals for interfacing the DSP with other systems. It contains tow Gigabit Ethernet ports that support a data rate of 1 Gbps. One of those ports has been connected to the image acquisition system.

2.3. Image acquisition system

Beef meat images were captured by the GigEPRO camera series from New Electronic Technology. It's the GP1503C model. The image resolution is 2592 × 1944 pixels (New Electronic Technology, 2013). This camera is compatible with GigE Vision protocol which is a communication protocol based on the Ethernet protocol for the transfer of uncompressed images. It allows easy interfacing between the GigE Vision device and the network card using a standard CAT-5 cable (Automated Imaging association, 2009).

The camera has been connected to the Gigabit Ethernet port of C6687 DSP using a standard CAT-5 cable. The transfer data rate between the camera and the DSP is equal to 1 Gbps. A software layer has been developed to configure the camera parameters and to start image acquisition using GigE Vision protocol. Each acquired image is a RGB image with a size of 15 MB. The measured time that takes each image acquisition is about 20 ms.

Beef meat images were captured each day forming a dataset of eighty-one images (1 image/ day). The illumination was achieved with 2 Philips fluorescent lights. The light bulbs were mounted all around the steak sample at about a 45 incidence angle from the steak surface imaged and they were heavily diffused. The same exposure and focal distance were used for all the images. The distance from the bottom of the camera lens to the sample surface was set was 20 cm. Preliminary tests show that this distance gives clear images without blurring. The image of each sample was taken and stored in Bitmap format for image processing and analysis.

2.4. Image processing

Color is one of most important quality traits of meat that the consumers check before purchase (Mancini and Hunt, 2005). In the customer's views, freshness is related to bright red in red meats (Chena et al., 2010). Fresh beef meat is expected to have a uniform reddish color. Therefore most customers distinguish against beef that is dark red or purple which they think is stale.

In order to measure changes of color in beef meat surface, parameters of eighty-one beef meat HSI images captured during nine days were used to build the classification models. Mean, variance, standard deviation and interquartile range features were calculated from a window of (200 × 200) pixels from eachimage. The HSI color model can be compared to how the human eyes perceive colors and then makes it ideal for developing image processing algorithms. Thus, hue describes the color itself in the form of an angle between [0,360] degrees. Saturation indicates the degree of the color purity, and describes how the color is polluted with white light. On the other hand, intensity characterizes the luminance information. It has to be stressed that for