**COMPUTER VISION SYSTEM FOR MEAT QUALITY EVALUATION**

**WITH CONVOLUTIONAL NEURAL NETWORK**

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**INTRODUCTION**

Meat quality is the characteristic of meat that is acceptable to consumers. This includes external factors such as appearance, texture and flavor; and internal factors such as chemical and microbiological characteristics (Baiano, 2017) and (Lonergan, Topel and Marple, 2019). Consumers’ meat purchasing decisions are heavily influenced by product appearance, particularly, color and marbling (Bargava and Bansal, 2019).

Globally, pork is the most consumed meat (15.8 kg/capita/year), followed by poultry (13.6 kg/capita/year), beef (9.6 kg/capita/year) and lastly sheep and goat meat (1.9 kg/capita/year) (Gokirmali and Bayram, 2017). Consumers’ meat purchasing decisions are influenced more by product appearance, such as color and marbling, than any other quality factor (Fonti-Furnols et al., 2015).

**Statement of the Problem**

Presently there are two methods used to evaluate meat quality. These are sensory evaluation and objective evaluation. Sensory evaluation is carried out by highly trained inspectors, involving the use of sight and smell (Kartika, Rivai and Purwanto, 2018). This can lead to inconsistent, subjective and variable results due to differences in human response (Sun, Young, Liu, Bachmeier, Somers, Chen and Newman, 2016). On the other hand, objective evaluation such as chemical and microbiological analyses are more reliable than sensory evaluation. However, they are destructive, tedious, time-consuming and costly (Mladenov, Penchev, and Dejanov, 2015) and (Santana, Geronimo, Mastelini, Carvalho, Barbin, Ida and Barbon, 2018). These suggest that a new technology that is rapid, accurate, non-destructive and highly repeatable could be beneficial. The potential of using computer vision system in the food industry has long been recognized. Computer vision system (CVS) tries to clone human assessment of color, content, shape and texture via its three main elements: camera, lighting and image analysis software. Hence, it has the ability to inspect samples and analyze differences among samples in an objective and non-destructive manner. Supported by learning algorithms, CVS provides judgments accurately, quickly and consistently.

The researcher would like to use this technology to develop a system that will be able to classify pork meat into categories according to quality in an objective and non-destructive manner.

**Objectives of the Study**

The general objective of the study is to develop a device that will evaluate pork meat quality using computer vision system with convolutional neural network. Specifically, the study aimed to:

1. Construct a computer vision system for meat quality evaluation with convolutional neural network using Agile methodology;
2. Determine the evaluation of meat inspectors and IT Practitioners of the system using ISO25010;
3. Determine the difference on the evaluation of the meat inspectors and IT Practitioners on the system, and;
4. Discuss the implications of the results of the study.

**Significance of the Study**

There were a variety of reasons why it was important to undertake this research. These reasons are brought by the possibilities presented by technology use in pork meat quality evaluation.

**Meat Inspectors.** Meat inspectors play a vital role in keeping the meat in the market safe for consumption and of quality. In this regard, providing an alternative tool that provides results in a fast manner can at least shorten the time they spend on meat visual inspection process.

**Consumers.** The consumers can get an assurance that pork meat quality in the market are checked using current imaging technology.

**NMIS Administrators.** The administrators can translate the information derived from the results of this study into effective planning and implementation of a new method of visual inspection of pork meat.

**Future researchers.** Researchers of similar undertaking can find the study useful and may be used as basis for their own design and development of a system for meat quality evaluation.

**Scope and Limitation of the Study**

This study focused on the classification of meat according to quality based on color, texture and exudation: PSE-pale, soft, exudative; RFN-reddish pink, firm, non-exudative; and DFD-dark, firm, dry. The researcher developed a computer vision system for meat quality evaluation which analyzed the quality of pork meat samples using convolutional neural network architecture, specifically MobileNet. Open source scripts for retraining the neural network was provided by Tensorflow. The device can perform objective, non-destructive classification and can provide immediate results via a liquid crystal display (LCD). These were implemented in the Raspberry pi platform running on Raspbian Buster operating system.

The initial testing of the device which included the classification of pork meat samples based on pH, color, texture and exudation was conducted on the same day in similar environmental conditions.

The study was conducted in the meat sections of Silang Public Market, Tagaytay City Market, and Kadiwa Market, all in the province of Cavite from August to November 2019.

The respondents of the study were meat inspectors from NMIS and IT practitioners. Survey questionnaires were distributed after which data were collected, analyzed and interpreted.

**Time and Place of the Study**

The study was conducted in the meat sections of Silang Public Market, Tagaytay City Market, and Kadiwa Market, all in the province of Cavite from August to November 2019.

**Definition of Terms**

The following terms are defined operationally in order to have a clearer understanding in this study.

**Color** refers to a phenomenon of light and visual perception that enables one to differentiate otherwise identical objects.

**Exudation** refers to the degree of oozing of liquid substance from meat.

**Functionality Suitability** refers to the degree to which the device provides function that meet stated and implied needs when used under specified conditions.

**Performance Efficiency** refers to the set of attributes that bear on the relationship between the level of performance of the device and the amount of resources used, under stated conditions.

**pH** refers to the degree of acidity of meat.

**Portability** refers to the degree of effectiveness and efficiency with which the device can be transferred from one environment to the other.

**Reliability** refers to the degree to which the device performs specified functions under specified conditions for a specified period of time.

**Usability** refers to the degree the device can be used by specified users to achieved specified goals with effectiveness, efficiency and satisfaction in a specified context of use.

**Texture** refers to the degree of firmness of meat.

**Conceptual Framework**

Research and development refers to the activities undertaken by individuals in developing new services, products, or improving services or products. Research and development constitutes the first stage of development of a potential new service or product. According to Sugiyono (2014) research and development is a method used to produce a certain product, and test the effectiveness of the product. The steps in this method are usually referred as R & D cycle which consist of: (1) research analysis, needs assessment, and proof of concept; (2) product planning and design; (3) preliminary product development; (4) preliminary field testing; (5) product revision; (6) main field testing; (7) final product revision; and (8) dissemination and implementation (Mufadhol, 2017). Most product development projects can be divided into these stages and can be modelled using Input Process Output. The Input Process Output (IPO) model is a functional model of a general system. It identifies the inputs (information, ideas, and resources used), processes (actions taken using the inputs), and outputs (results of the processing).

**Research Paradigm**

The research paradigm of this study found its basis from the above conceptual framework and the concepts, theories and discussions in the Review of Related Literature.

**Input**

Knowledge requirements

* Meat Quality Evaluation
* Computer Vision
* Machine Learning

Software requirements

* Tensorflow
* Python
* Raspbian Buster

Hardware requirements:

* Raspberry pi
* Picamera
* LCD

**Process**

Agile Software Development Methodology

* Requirements
* Planning
* Designing
* Development
* Release
* Track and Monitor

Evaluation Criteria

* Functional suitability
* Performance Efficiency
* Usability
* Reliability
* Portability

**Output**

Computer Vision System for Meat Quality Evaluation with Convolutional Neural Network

**Feedback**

Figure 1. Research Paradigm

Figure 1 shows the research paradigm of the study using the IPO model. The input block consists of the knowledge requirements, software and hardware requirements. Knowledge requirements are the basic information needed to understand in pursuing the study. Software requirements involve knowledge and skills on certain computer programming language and software library packages in order to create a workable system. Hardware requirements include the materials and equipment to be used in the development of the system.

The process block shows the Agile software development model stages undertaken to create a working system.

The output block shows the developed computer vision system for meat quality evaluation.

**REVIEW OF RELATED LITERATURE**

This chapter presents the related literature and studies which are found to have a direct bearing to the present investigation in the study about meat quality evaluation, computer vision systems and machine learning.

**Meat Quality Evaluation**

In general, meat quality is the quality characteristics of meat that is acceptable to consumers. This includes external factors such as appearance (size, shape, color and consistency), texture, and flavor; and internal factors such as chemical, and microbial characteristics (Baiano, 2017) and (Lonergan, Topel, & Marple, 2019). Consumers routinely use product color and appearance to select or reject meat products and is therefore a very important quality attribute (Bhargava & Bansal, 2018).

Presently, traditional way of evaluating meat quality is still widely used. This requires direct contact to a meat sample through human visual inspection and odor assessment by human nose (Kartika, Rivai, & Purwanto, 2018). However, meat quality evaluation by human sense is difficult to be quantified due to inconsistent, error prone measurement (Sun et al., 2016).

Instrumental techniques are also used. These are chemical and microbiological techniques (Font-i-Furnols, Candek-Potokar, Maltin, & Prevolnik Povše, 2015). Among these are Kjedal total nitrogen determination to determine meat protein content; oven methodology to determine moisture content; Soxhlet extraction and Folch method to determine fat content; marbling to measure the appearance of evenly distributed white flecks of fatty tissue between bundles of muscles fibers; measurement of pH value using a pH meter; bag method for water holding capacity; meat chromatography and spectroscopy to assess meat color; texture analysis and fatty acids analysis. These techniques are more objective than sensory evaluation, but are tedious, time consuming, destructive and costly (Herrero, Hernandez, Jiménez-Colmenero, & Perez, 2017), (Mladenov, Penchev, & Dejanov, 2015) and (Santana et al., 2018).

Over the years, non-destructive techniques are also introduced. Non-destructive means that the sample can be examined without altering it in any way. Some of these are image processing (Bhargava & Bansal, 2018), (Di Rosa, Leone, Cheli, & Chiofalo, 2017) and (Sun et al., 2018); spectroscopy (Cozzolino & Murray, 2012), (Adiani, Gupta, Ambolikar, & Variyar, 2018), (Argyri et al., 2013), (Geronimo et al., 2019), (Estelles-Lopez et al., 2017) and (Jiang et al., 2018); odor imaging (Salinas et al., 2014); electronic nose (Huang, Zhao, Chen, & Zhang, 2014), (Loutfi, Coradeschi, Mani, Shankar, & Rayappan, 2015), (Papadopoulou, Panagou, Mohareb, & Nychas, 2013), (Wijaya, Sarno, & Zulaika, 2019) and (Wojnowski, Majchrzak, Dymerski, Gębicki, & Namieśnik, 2017); and electronic tongue (Zhang, Wang, Liu, Xu, & Zhou, 2012). Image processing can provide ample spatial data while spectroscopy can provide abundant spectral data. Either spatial or spectral data may relate to sensory, chemical and physical properties of meat. But it must be noted that the richness of spectral data also results in difficulties in data processing (A. I. Ropodi, Panagou, & Nychas, 2016). Odor imaging is an olfaction system based on colorimetric sensor array (Xiao-wei, Xiao-bo, Ji-yong, Zhi-hua, & Jie-wen, 2018). Although odor imaging has advantages, its scope is limited because it can only be used for odorous products. An electronic nose is an artificial olfaction model which can detect, identify and classify an aroma of a sample (Wojnowski et al., 2017) and (Timsorn, Thoopboochagorn, Lertwattanasakul, & Wongchoosuk, 2016). An electronic tongue uses sensors to discriminate, identify and quantify a sample (Gil-Sánchez, Martínez-Máñez, Barat, & Garcia-Breijo, 2016) and (Lee et al., 2019). Both the electronic nose and electronic tongue have their own advantages but may fall short because of minimal training dataset.

**Classification**

The essential feature for food quality evaluation is classification which contribute a structure in which artificial simulation of human thinking is done to guide humans form sophisticated judgments instantaneously, correctly and persistently. By using image processing techniques, fruits and vegetables images can be described by set of features such as color, size, shape and texture. These features are used to form training set, then classification algorithm is applied to extract knowledge base which make a decision of unknown case. In computer vision system, a wide variety of methods: KNN, SVM, Artificial Neural Network (ANN), Deep Learning/Convolutional Neural Network (CNN) have been developed for classification in food quality evaluation (Bhargava and Bansal, 2018).

For the analysis of classification results, confusion matrix is universally accepted for accuracy reporting. The overall accuracy of the matrix which is computed by the weighting of the percentage of all correctly-classified images in each assigned category, is used to quantify the classification accuracy. Moreover, a high value of kappa coefficient indicates higher reliability of classification results (Lam, Lau & Li, 2000)

**Computer Vision System**

Computer vision is the science that develops theoretical and algorithmic basis to automatically extract and analyze useful information about physical objects from images (Sun et al., 2018). In general, computer vision system consists of three main components: a lighting system, a camera and a computer (A. I. Ropodi et al., 2016). Properly designed lighting can improve the precision of analysis and decrease analysis time. A camera is used to capture the image of the sample to be sent to the computer for processing and analysis.

Image processing and image analysis are at the core of computer vision (Xu & Sun, 2017). Image processing involves a series of operation that enhance the quality of an image. Image analysis is the process of distinguishing the objects from the background and producing quantitative information. In a sense, computer vision extracts quantitative information such as color, shape, size, surface defects and contamination (Fan et al., 2013) from digital images using image processing and analysis, resulting in a non-contact and fast measurement (A. P. A. d. C. Barbon et al., 2017) and (Sanaeifar, Bakhshipour, & de la Guardia, 2016). With the recent advancements in algorithms and computer hardware, computer vision has the potential to provide even better evaluations of food quality (Fan et al., 2013) and (A. P. A. C. Barbon et al., 2016).

Challenges remain in reducing the size of computer vision systems, developing hardware suitable for use in industrial environments, and designing control software with an easy-to-use graphical user interface (GUI). Most hyperspectral imaging, multispectral imaging, and Raman spectroscopic systems are bulky and are limited to laboratory use. A compact system that is suitable for industrial or commercial use will be attractive to the meat industry (Alcayde, Elijorde & Byun, 2019).

**Machine Learning Algorithm**

Machine learning is a computational method for automatic learning from experience and improves the performance to make more accurate predictions (Kaur & Kumari, 2018). Machine learning employs algorithms that fits data to a model. Fitting data to make predictions is the basic process of learning (Maryan, Hoque, Michael, Ioup, & Abdelguerfi, 2019). Machine learning is classified as supervised or unsupervised learning (Shobha & Rangaswamy, 2018). In supervised learning, the data are labeled in classes, whereas in unsupervised learning, the data are not labeled. Majority of machine learning algorithms use supervised learning (Silva, Teixeira, Silva, Brommonschenkel, & Fontes, 2019) where the system is trained with the inputs and respective responses and then used for the prediction of the response of new data (Kaur & Kumari, 2018).

Machine learning algorithms are quickly moving into many fields, with one of the most recognizable being applications in speech recognition and computer vision (Orus Perez, 2019).

Deep Learning (LeCun et al., 2015) has drastically emerged as the paradigm of image processing, improving the state-of-the-art in many domains, including object detection and object recognition. Differently from conventional image recognition methods, deep learning architectures like Convolutional Neural Networks (CNNs) can use the raw image as input as they incorporate the feature construction step directly into the learning process, by updating their parameters and connections as a function of the error on a set of training data.

Transfer learning is a method of storing knowledge gained from a particular problem and re-applying it to a new problem (Pan & Young, 2010)

**MobileNet**

MobileNet is a training architecture developed to function on mobile and embedded vision applications (Howard et.al, 2017). MobileNet is used to reduce the computation and model size.

**Related Studies**

**Nondestructive detection of total volatile basic nitrogen (TVB-N) content in pork meat by integrating hyper spectral imaging and colorimetric sensor combined with a nonlinear data fusion**

Li, Chen, Zhao and Wu (2015) developed a new strategy for measurement of total volatile basic nitrogen content, an important index used to assess freshness, in pork meat by integrating two non-destructive sensing tools of hyperspectral imaging and colorimetric sensors.

This work shows the feasibility in determination of TVB-N content in pork meat using hyperspectral imaging and colorimetric sensors. It also shows that the proposed method in this work has a high potential in real-time monitoring pork meat’s quality and safety (Li, Chen, Zhao, & Wu, 2015).

http: dx.doi.org/10.1016/j.lwt.2015.03.052

**Applications of computer vision for assessing quality of agri-products: a review of recent research advances**

Ma, Sun, Qu, Liu, Pu, Gao and Zeng (2014) review and present the fundamentals and instrumentation of computer vision systems, details of applications in quality assessment of agri-food products from the years 2007 to 2013, and also discuss its future trends.

This review shows that computer vision can be used to extract and analyze useful information from agri-food products to perform detection, recognition and classification. Products that can be detected include meat, fruits, vegetables, nuts, grains and so on. T. dx.doi.org/10.1080/10408398.2013.873885

**Rapid detection of frozen-then-thawed minced beef using multispectral imaging and Fourier transform infrared spectroscopy**

Ropodi (2017) developed an advanced, effective and relatively low cost solution for quality assurance using multispectral imaging (MSI), Fourier Transform Infrared Spectrometry (FTIR), and application of advanced data analysis and machine learning methodologies.

The results show that in all cases MSI and FTIR showed great potential for use in a fast, accurate way, whether the purpose is spoilage estimation or fraud detection. What is interesting to note is that various methods worked well for one dataset but not so well for another (Athina I. Ropodi, Panagou, & Nychas, 2018).

dx.doi.org/10.1016/j.meatsci.2017.09.016

**Prediction of pork color attributes using computer vision system**

Sun, Young, Liu, Bachmeier, Somers, Chen and Newman (2016) used color image processing and regression methods to evaluate color scores of pork center cut loin samples. Eighteen color features were extracted from three different color spaces and were shown to have useful information regarding pork color. It was concluded that the prediction of pork color using computer vision is encouraged for use in further research and industry application. Further research is needed to validate and improve the accuracy of the vision system (Sun et al., 2016). dx.doi.org/10.1016/j.meatsci.2015.11.009

**Prediction of pork loin quality using online computer vision system and artificial intelligence model**

Sun, Young, Liu and Newman (2018) developed a computer vision system for objective measurement of pork loin under industry speed requirement. Image features were extracted from pork loin color images. Artificial intelligence prediction model was established for pork color and marbling quality grades. The results showed that the computer vision system with artificial intelligence modeling reached a high prediction accuracy (Sun et al., 2018).

doi.org/10.1016/j.meatsci.2018.03.005

**Exploiting multispectral imaging for non-invasive contamination assessment and mapping of meat samples**

Tsakanikas, Pavlidis, Panagou and Nychas (2016) evaluated multispectral imaging in terms of monitoring aerobically packaged beef fillet spoilage. A support vector regression model was developed to provide quantitative estimations of microbial counts during storage. Results exhibit good performance with overall correct classification rate for two quality classes for model validation (Tsakanikas, Pavlidis, Panagou, & Nychas, 2016).

dx.doi.org/10.1016/j.talanta.2016.09.019

**Non-destructive prediction of thiobarbituric acid reactive substances (TBARS) value for freshness evaluation of chicken meat using hyperspectral imaging**

Xiong, Sun, Pu, Xie, Han and Luo (2015) examined the potential of hyperspectral imaging (HSI) for rapid prediction of 2-thiobarbituric acid reactive substances (TBARS) content in chicken meat during refrigerated storage. Using spectral data and reference values of TBARS, a partial least square regression model was established and yielded acceptable results. The encouraging results of this study demonstrated that HSI is suitable for determination of TBARS values for freshness evaluation of chicken meat (Xiong et al., 2015).

dx.doi.org/10.1016/j.foodchem.2015.01.116

**Synthesis**

The proposed system, computer vision system for meat quality evaluation aims to classify pork meat according to quality using computer vision with convolutional neural network. The study of Li, Chen, Zhao and Wu (2015), Ma, et. al (2014), Ropodi (2017), Sun, et. al (2016), Sun, Young, Liu and Newman (2018), Tsakanikas, Pavlidis, Panagou and Nychas (2016), Xiong, Sun, Pu, Xie, Han and Luo (2015) are all closely related with the study because the studies stated are all implemented using computer vision system. The result of the studies mentioned all draw to a conclusion that describes the effectivity of using image processing, image analysis, and learning algorithm to evaluate meat quality. Also, Ma, et. al (2014) and Sun, et. al (2016) suggest that further research must be done to validate and improve the accuracy of the computer vision system.

**METHODOLOGY**

This chapter presents the research methodologies needed in the study to ensure the validity and reliability of the study. Included in this chapter are research design, population and sampling technique, respondents, research instrument, data gathering and procedure and statistical analysis.

**Research Design**

The researcher used the developmental method for the systematic study of designing, developing and evaluating processes and products that must meet the criteria of internal consistency and effectiveness. The researcher used the Agile software development methodology. Agile methodology is an iterative, and incremental process model that focuses on adaptability to changing product requirements through rapid delivery of working product features and end-user participation.

The researcher also employed the descriptive approach to determine the functional suitability, performance efficiency, compatibility, usability, reliability, maintainability, and portability of the system.

**Population and Sampling Design**

After asking the Administrative Section Head of the NMIS Region IV-A, the total number of meat inspectors is twenty-eight (30) and ten (10) IT practitioners. The researcher also took respondents from Cavite State University-Silang Campus from a total of twenty-seven (27) IT practitioners. The number of respondents are obtained using the Slovin’s Formula using 5% margin of error.

n = N/(1+Ne2 )

where:

n = sample size

N = total population of respondents

e = margin of error

The total number of respondents is fifty-eight (58) composed of twenty-eight (28) meat inspectors and thirty (30) IT practitioners.

**Description of the Respondents**

The respondents of this study are 28 meat inspectors from the NMIS Region IV-A and 30 IT practitioners from NMIS and Cavite State University-Silang Campus. The participants from NMIS were chosen for this study because of their awareness and knowledge about meat inspection and classification, while the participants from Cavite State University-Silang Campus were chosen because of their knowledge in the field of Information Technology, specifically system development theories and practice.

**Research Instrument**

The researcher used survey questionnaire, interview, and observation as research instruments.

The researcher adapted the ISO25010 standardized survey questionnaire answered by the respondents who evaluated the functional suitability, performance efficiency, usability, reliability and portability of the system.

The distribution of the survey questionnaire was facilitated by the researcher. The researcher personally distributed the questionnaires to the meat inspectors and IT practitioners from the NMIS Region IV-A and IT practitioners from Cavite State University-Silang Campus.

The researcher also had an informal interview with a selected meat inspector and asked him to discuss the process of meat visual inspection.

Pork meat samples were taken for pH measurement, then its color-texture-exudation were also observed, recorded and analyzed.

The researcher also went on observing pork meat based on color-texture-exudation using the developed computer vision system for meat quality evaluation in three (3) different public markets in Cavite on three (3) different times of the day: 5:00 am – 6:00 am, 12:00 nn -1:00 pm, and 4:00 pm. The observations were recorded and analyzed.

**Data Analysis**

The researcher used different statistical tools in evaluating the results of collected information such as weighted mean and z-test.

**Weighted Mean** was used to determine the average of the response on the rating of evaluation of the system.

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where:

x = weighted mean

∑fx = sum of the products of frequencies and weight

N = total number of respondents

Five Point Rating Scale was used to answer the survey questionnaire. The survey was answered by each indicator and was numerically rated using the scoring presented below.

**Five Point Rating Scale**

Weight Mean Value Verbal Interpretation

5 4.50 – 5.00 Highly Acceptable

4 3.50 – 4.49 Acceptable

3 2.50 – 3.49 Moderately Acceptable

2 1.50 – 2.49 Unacceptable

1 1.00 -1.49 Highly Unacceptable

Percentage was used to standardize the size to indicate the frequency of occurrence of a category per 100 cases.

Percent (%) = 100 x

where:

f = frequency of occurrence

n = total number of cases in the distribution

z-test was used to determine whether there is a difference between the means of two samples.

where:

x1 = mean of sample 1

x2 = mean of sample 2

S1 = standard deviation of sample 1

S2 = standard deviation of sample 2

n1 = size of sample 1

n2 = size of sample 2