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Hyperspectral transmittance imaging of the shell-free cooked clam *Mulinia edulis* for parasite detection

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ABSTRACT

The clam *Mulinia edulis* is occasionally infected by the parasite *Edotea magellanica*. In this paper the normalized optical transmittance of the clam and its parasite have been disclosed for the first time using a hyperspectral imaging system. It has been identified that, in the spectral band of 600–950 nm, the normalized optical transmittance of clam's mantle cavity changes in the presence or absence of the parasite. This relative change in the normalized optical transmittance has been used as an effective spectral feature for designing parasite detectors. As a proof of concept two detectors have been designed. The first detector, which relies on all the hyperspectral information, achieved a perfect detection accuracy in identifying parasite-infected clams. The second detector, which is based on a reduced number of hyperspectral bands, achieved an 85% detection accuracy. These results provide insights on the fundamental trade-off between detection accuracy and the amount of hyperspectral information for parasite detection in clams.

1. Introduction

One of the main goals of the Chilean economy is to become a world-class food leading producer. It can be stated that the Chilean seafood industry is one of the most important development clusters in Chile, Perez-Aleman (2005). In order to fulfill international food quality and safety standards, Chilean seafood industry is currently demanding for engineering solutions that must be supplied from both fundamental and applied research.

The harvesting and processing of the clam *Mulinia edulis* has become a growing market not only in Chile but also around the World. Unfortunately, the Chilean seafood industry must deal with the problem of discarding, at the production line, all those clams that are infected by a very particular parasite called *Edotea magellanica*. Fig. 1a and b shows pictures, taken with a high-resolution RGB camera, of both the *Mulinia edulis* clam and the *Edotea magellanica* parasite. Scientific studies have shown both, that the parasite infects the clams only at some seasons of the year and that has a low frequency of appearance. In fact, Gonzalez and Jaramillo (1991) reported that between 1.5% and 4.5% of the clams are seasonally infected by the parasite. Moreover, they also reported that the parasite is neither dangerous to human health nor affects the meat of the clams. However, parasites must be removed to fulfill the food quality standards of major seafood markets. Currently, the parasite detection and removal is carried out manually by human operators in Chilean industries; consequently, the process becomes expensive, slow, and inaccurate. Further, what makes the problem a very complicated task is that the parasite is not visible because it hides below the surface/skin of the clam at a very specific anatomical region known as the clam's mantle cavity, Gonzalez and Jaramillo (1991).

The most common technique used in food industry to detect hidden objects is X-rays. For instance, Tao and Ibarra (2000) used X-rays for detecting bones in poultry. X-rays technology was successfully used in such an application due to there is a noticeable density difference between poultry meat and their bones. Even though X-rays appeared to be a straightforward solution to the problem of parasite detection in clams, such technology was discarded because of two practical constraints. First, the tissue density of the clam and its parasite are very similar; they cannot be distinguished as it was observed in practice and reported in Coelho (2011). Second, the cost of the X-rays technology is a major constraint for small Chilean seafood industries.

Advanced optical technologies have lately been used in the food industry to detect hidden objects, to control food quality, and to conduct spectral analysis, Sun (2010). There is a considerable body

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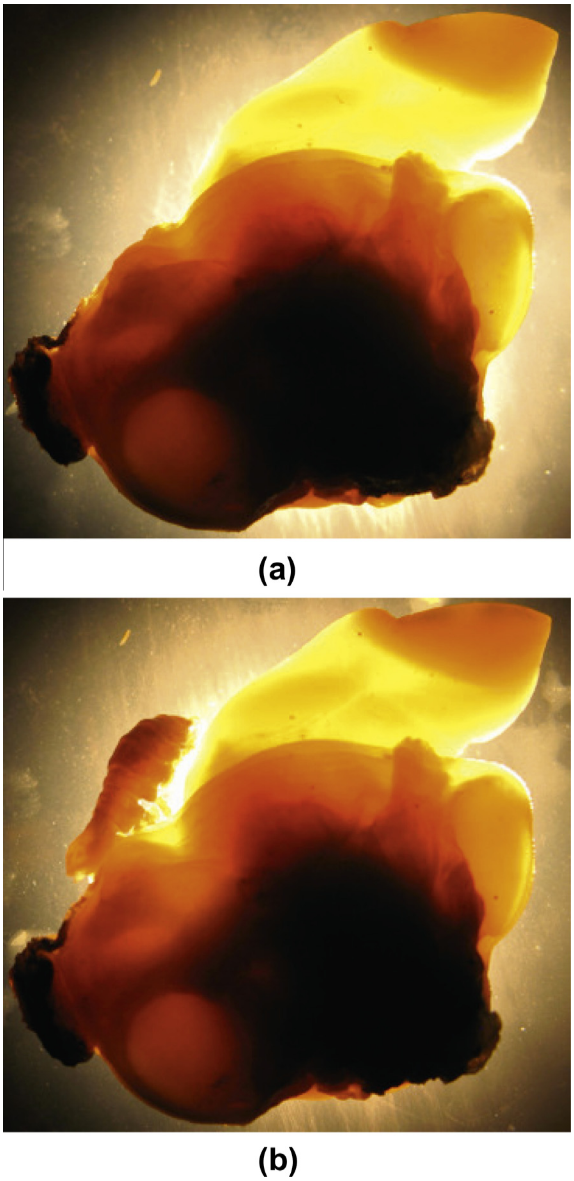

Fig. 1. The *Mulinia edulis* clam and the *Edotea magellanica* parasite. These images were captured with a visible band camera, referenced in Soto et al. (2011). (a) The parasite was located inside of the clam's mantle. (b) For comparison, the parasite was placed outside of the clam.

of work on applied optical and spectral information processing, specially in hyperspectral image analysis, Grahn and Geladi (2007). For instance, in the work by Mehl et al. (2002), a reflection hyperspectral camera was used to determine the spectral signature of apples in order to detect bruises. Moreover, the information contained in the spectral signature was also used to develop a three channel, multispectral system for the apple industry. The major disadvantage in their work is that the detection process relied on human intervention because apple samples had to be manually oriented prior acquiring spectral information. Ariana et al. (2006) proposed using a reflection hyperspectral camera, in the Near Infrared range, for detecting bruises on pickling cucumbers. Additionally, an application for discriminating muscular zones in lambs, which exploited Near Infrared hyperspectral images, was presented in the work by Kamruzzaman et al. (2011). In their work, researchers investigated on spectral band selection for the optimal discrimination of the muscular zones. It must be commented that the optical reflection mode cannot be used to solve the problem at hand because the parasite appears to be hidden inside of the clam.

The optical transmission mode has also been used in the food industry to detect hidden objects. For instance, the optical transmission mode, in conjunction with a hyperspectral system, were used by Sivertsen et al. (2011) to develop an automatic, image-based hyperspectral method for parasite detection in the fish industry. The researchers reported in their work an overall accuracy of 58% in detecting all kinds of parasites. In the same direction, Wold et al. (2001) described also a method for detecting parasites in fish fillets, which was based on both separating specific spectral bands of interest and classifying the parasites using a statistical method. Soto et al. (2011) have already proposed a method to automatically classify *Mulinia edulis* clams infected with the *Edotea magellanica* parasite based on a high-resolution RGB camera. The automatic parasite detection system was realized by means of a pattern recognition method that relied on the quantitative description of clam's regions and used a decision tree to classify candidate parasite zones. The main results achieved by this classifier are a positive detection rate of 86% and classification accuracy of 87%. In order to obtain consistent results, a mechanism for enforcing a uniform clam thickness during the image acquisition was implemented. It is worth mentioning that in Soto et al. (2011), the research problem focused on developing an automatic vision system for classifying infected clams, while in this work the focus is the identification of specific spectral optical transmittance features for the biological clam-parasite tandem, in its natural thickness and shape.

The aim of this paper is to find optical transmittance features of the clam-parasite tandem in the spectral domain by means of advanced hyperspectral imaging technologies. The normalized optical transmittance was measured at specific regions of the clam where the parasite is most likely to be found. To the best of our knowledge, the normalized transmittance spectral properties of such regions have been disclosed for the first time in this paper. Empowered with this spectral information, we identified the spectral band where the mantle cavity of the clam exhibits different normalized optical transmittance properties in the presence or absence of the parasite. Specifically, we observed that, when a parasite hides inside of the clam's mantle cavity, the normalized optical transmittance of the cavity heavily decreased in the spectral band between 600 and 950 nm, as compared to the normalized transmittance of a parasite free mantle cavity. Consequently, the experimental clam-mantle-parasite normalized transmittance curves presented in this work can be regarded as key features to develop parasite detection systems for the clam industry.

In addition, we have described in this paper two different approaches for detecting a parasite hidden in a clam. The first approach uses the entire spectral information in the transmission curves to devise a simple parasite detection scheme. The devised scheme achieved a perfect detection accuracy, however, such scheme turned out to be unattractive for the clam industry because it may need the use of expensive imagers. The second approach uses information from three spectral wavelengths only, and was obtained after statistically analyzing clam's hyperspectral data. The three selected spectral bands were used to create reference values for parasite free and parasite infected clams, and the Mahalanobis distance between test clams and the reference values was used to detect a parasite. Furthermore, once a parasite has been detected, a simple yet effective image segmentation technique was used for identifying the parasite location within a clam.

The rest of the paper was organized as follows. The data-sample preparation, the experimental set-up, the acquisition of the hyperspectral information, and the calibration of the data set have been described in Section 2. The main experimental results and examples of their application in parasite detection and localization have been presented in Section 3. Finally, in Section 4 the main conclusions and future work are summarized.