Computers in Industry 99 (2018) 119–129

Contents lists available at ScienceDirect

Computers in Industry

journal homepage: www.elsevier.com/locate/compind

Automated vision system for quality inspection of slate slabs

C. Iglesias[a,*], J. Martínez[b], J. Taboada[a]

[a] Department of Natural Resources and Environmental Engineering, University of Vigo, Vigo, 36310, Spain
[b] Centro Universitario de la Defensa, Escuela Naval Militar, Marín, 36920, Spain

ARTICLE INFO

Keywords:
Artificial vision
Machine vision
Inspection
Natural slate

ABSTRACT

The natural properties of slate have made it a valuable resource for construction purposes, especially for roofing. However, slate slabs must meet certain requirements to ensure their suitability as roofing material, so the manufacturing process includes a final quality inspection stage in which an expert manually inspects each individual slab and checks for the presence of traits inherent to this type of rock.

We describe an automated inspection system for examining slate slabs, based on capturing data with a 3D colour camera and studying slate slab traits using computer vision algorithms specifically developed for this purpose. We tested the method on a set of 70 slate slabs (from a Spanish mine) that had previously been examined by an expert. The prototype system performed well, as the inspection algorithms were able to accurately detect traits and characterize the slabs. The detection of sulphides was tested using calibration slabs with artificial sulphides of different shapes, sizes and colours. The algorithms developed for the detection of traits proved to be robust.

1. Introduction

Slate is a valuable natural resource used in construction due to its natural characteristics. It is waterproof and fireproof, even in the form of slim slabs, and has very low thermal and electrical conductivity. As it is relatively lightweight, it has been widely used for roofing. Slate is extracted from open-pit and underground mines in a process that comprises several steps that concludes with the preparation of the commercial product. The final step before distribution for sale is quality evaluation (i.e., grading) of individual slabs by an expert who inspects slabs for defects or traits, assesses their properties and assigns a quality grade.

While different stages of the industrial process have been mechanized, including cutting [1,2] and palletizing [3], grading is still performed manually, with the inherent drawbacks of subjectivity, fatigue and the need for specific training [4].

Since slate, as well as other ornamental rocks, ceramics, wood, textiles, etc, are required to be aesthetically pleasing, their physical appearance needs to be evaluated [5]. Although appearance has traditionally been evaluated manually, in recent years considerable effort has been invested in objectively quantifying the properties of materials so that they can be assigned a certain quality or grade by a human expert.

In a highly competitive global marketplace, reliable and effective product quality assessment is key to maintaining high standards and, ultimately, to ensuring the success of a company. The use of automated graders based on artificial vision and artificial intelligence techniques can ensure more coherent quality standards, better reproducibility and more reliable product records [5,6].

This research describes an artificial vision system built to evaluate slate slabs in terms of quality. It is based on the acquisition of 3D and colour 2D data that are subsequently analysed using image processing procedures. As a result of these acquisition and inspection stages, the slabs are characterised geometrically and aesthetically and are eventually assigned a quality grade.

The paper is laid out as follows. Section 2 consists of a literature review of vision systems and image processing approaches; Section 3 describes the traits that define slate slab quality; Section 4 describes our automated vision system and compares previous and new prototypes; Section 5 explains how traits are detected; Section 6 presents and discusses experimental results for a sample of slate slabs; and finally, Section 7 contains conclusions and describes future work.

2. Literature review

The detection of surface defects can be approached using several image analysis strategies. In a review of image processing algorithms applied to the detection of defects, Karimi and Asemani [6] distinguish between the following categories: (1) filtering methods; (2) structural techniques; (3) statistical methods; and (4) model-based techniques.

* Corresponding author.
E-mail addresses: carlaiglesias@uvigo.es (C. Iglesias), javier.martinez@cud.uvigo.es (J. Martínez), jtaboada@uvigo.es (J. Taboada).

https://doi.org/10.1016/j.compind.2018.03.030
Received 22 December 2016; Received in revised form 22 January 2018; Accepted 20 March 2018

Filtering methods are based on the use of mathematical filters, mathematical translations and pattern recognition techniques. In general terms, these methods need a reference pattern without noise, so they are suitable when the material is patterned and has periodic, directed properties [7,8].

The main structural techniques are edge detection algorithms and morphological methods. Edges, defined as the boundary between two different regions from the same image, can be detected using gradient, threshold or other algorithms that emphasize these boundaries [9]. Morphological methods use the morphology of binary or grayscale images to enhance, smooth and reduce noise in images using pixel neighbourhood [10].

Statistical methods include histogram curve properties, co-occurrence matrices, autocorrelation and fitted Weibull distributions. The histogram curve properties approach is a simple method to extract edges by thresholding, since the difference between intensity values for boundaries and the rest of the image is usually pronounced [11]. Co-occurrence matrices and autocorrelation are based on similarity between a pixel and its neighbours; while a co-occurrence matrix considers several directions and is useful to analyse the entropy and correlation of the image [12], autocorrelation finds patterns in the original image and so detects faulty images because of the existing difference in patterns [13]. As for fitted Weibull distributions, this method is based on dividing the image, calculating the histogram of the gradient and fitting a Weibull distribution to the histogram [6].

Model-based techniques use image processing models to analyse images and detect defects using model parameters. Hidden Markov models are one example, although they have the drawback of being complex to statistically compute [6]. Autoregressive models are another example, although they have the disadvantage that they need a training stage and results are non-deterministic and statistical in nature [6].

Several applications of machine vision systems based on the above-mentioned methods are described in the literature on quality evaluation in industrial sectors such as textiles [8,14,15], steel [16–19], food processing [20–23], timber [24–26] and ceramics [6,27–30]. Methods and applications for a wide variety of industrial materials are comprehensively reviewed elsewhere [31,5].

Regarding the methods used for the evaluation of textile products, two main problems can be distinguished. While vision systems can estimate physical properties such as fibre density and size [15] and can search for defects by means of image processing algorithms [8,14], fabric—unlike natural materials such as slate—is characterised by the fact that the structure is periodic, uniform and directed [8]. Thus, the detection of defects requires texture filters to break fabric uniformity in direction and frequency.

A similar case is that of steel products, where texture algorithms can be used to detect defects that break the surface homogeneity of uniformity and brightness [17–19]. In addition to appearance requirements, dimensional requirements are also important since manufacturing must be precise. Hence, many systems focus on dimensional analyses and feature metrology procedures [16].

Among the systems developed in the food processing field are systems to evaluate fruits such as oranges and apples [20,21] which are required to have a uniform shape and surface. Fruit evaluation strategies to detect bruised or morphologically defective fruit are similar to those for the above-mentioned systems.

Regarding timber, defects are detected, using morphology algorithms, on the basis of the presence and morphology of natural knots, whose number, size and shape determine the quality of the inspected wood [24,25]. Sorting according to appearance has also been studied, whereby colour analysis is used to match up parquet samples having similar colour characteristics [26].

Problems in the case of ceramic products are similar. Again, surface homogeneity is a key feature, so texture algorithms are used that detect defects such as cracks or pores [27,29,30]. Also, sorting based on colour has also been described [28] that uses the same strategy as that for timber [26].

Focusing on petrous materials, timber could be considered the most similar material, since it is a natural material and the shape resembles that of ornamental stone products (slabs in the form of flattish pieces). Unlike metal, fruit or ceramic products, timber and slate have heterogeneous surface properties and, unlike fabric, they have no patterns.

The inherent characteristics of rocks and their applications need to be borne in mind when it comes to defining quality and the strategy to analyse quality. The literature includes several studies of inspection and grading systems applied to ornamental rocks, specifically, granite, marble and slate.

Granite, of which many commercial varieties exist, is characterized basically by colour and texture (grain size). Its aesthetic defects are usually linked to the presence of veins or stains or to grain size and colour irregularities. Veins or stains normally reflect a pronounced change in texture; since they are visible to the human eye, defective slabs or sheets can be discarded from the very outset of the manufacturing process. The machine vision systems found in the literature focus more on ensuring homogeneity in granite batches offered for sale by grading according to appearance [32–35].

With marble slabs, colour, texture, dimensions and polish quality, among other properties, need to be evaluated in order to determine commercial grade. Several studies in the literature refer to the detection of defects in marble [36–39]; one study in particular [40], using greyscale images, histogram variances and RGB components, analyses varieties of marble based on colour and the amount and dispersion of fossils and algae in the slab surface with a view to discarding slabs with defects.

Slate, in direct contrast with marble, is dark grey or black in colour. This colour difference, among other variables, means that image analysis methods as used for marble are not directly applicable to slate. Slate texture and colour must therefore be evaluated differently from marble, whose quality can largely be determined from an analysis of histograms and of the relative numbers of clear pixels and points or specks [40].

Few studies have been performed on natural slate slab grading using artificial vision systems that combine software and hardware in order to obtain, process and analyse information obtained using digital cameras. Painted slates, however, have been studied in several research works [41–43]; using a visioning system consisting of a monochrome linear camera and collimated light illumination, slate slabs are inspected on exiting from a painting line for their geometric characteristics, the correct positioning of holes (punched in the slabs for subsequent installation), the homogeneity of the paint layer and possible painting defects.

No such system has been described, however, for natural slate, which has to be analysed for construction purposes in terms of mechanical strength, resistance to weathering, porosity, etc. The UNE-EN 12326-1:2005 standard describes requirements for natural stone and slate products for inclined roofs and external coatings [44]. Slate tends to have certain traits, among them, sulphides, white (flowerlike) staining, warping and surface irregularities. These traits, along with the geometry of the slabs, determine the commercial value and suitability of slate for specific applications in the international market [45].

Most of these traits (described in full in Section 3) are unique to slate since they are a consequence of its geological characteristics. This is the case of warping and kink-bands (fissuring), related to the 3D profile of the slabs, which require a specific detection procedure. Dimensional characteristics (material defects and false squaring) also need to be checked, but they do not imply metrology procedures: firstly, precision in length measurements is not essential since this is defined as a relationship between areas (material defects) or as a deviation from a right angle (false squaring). These traits can thus be analysed by means of structural techniques aimed at finding the edges of the slabs and analysing their area and perimeter.

As for sulphides and white (flowerlike) staining, from a practical