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INDUSTRIAL APPLICATIONS OF IMAGE PROCESSING

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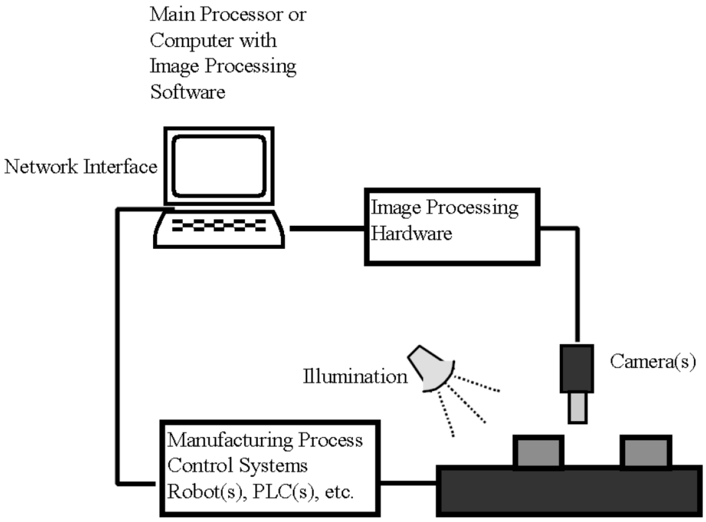
Abstract: *The recent advances in sensors quality and processing power provide us with excellent tools for designing more complex image processing and pattern recognition tasks. In this paper we review the existing applications of image processing and pattern recognition in industrial engineering. First we define the role of vision in an industrial. Then a dissemination of some image processing techniques, feature extraction, object recognition and industrial robotic guidance is presented. Moreover, examples of implementations of such techniques in industry are presented. Such implementations include automated visual inspection, process control, part identification, robots control. Finally, we present some conclusions regarding the investigated topics and directions for future investigation.*
Key words: image processing, computer vision, industrial engineering, automated visual inspection

Introduction

Traditionally, visual inspection and quality control are performed by people. Although people are very good at this task and sometimes even better than machines, they are much slower and they cannot work for long periods of time as their eyes get tired and need to relax. In many applications, information must be quickly and repetitively extracted, processed and decisions have to be made. Advances in image processing technology are creating new perspectives in increasing productivity, quality and efficiency in a wide range of industrial applications. A vision system has become a vital component of advanced manufacturing systems, for two main reasons. Firstly, it provides a means of controlling quality during manufacturing of goods, and secondly, robotic assemblies can be provided with the necessary information in order to assemble complex products from a set of basic components. In certain environments inspection can be dangerous or difficult. Machine vision can replace human inspection in such cases. Automated assembly lines make flexible manufacture a reality, thus costs due to underuse of production lines are dramatically reduced.

Figure 1: A general industrial vision system



Source: (Malamas, 2003)

Figure 1 illustrates the structure of a general purpose industrial vision system. Firstly, the scene needs to be properly illuminated and arranged in order to facilitate a good image acquisition. Images are commonly acquired by one or more cameras placed in the neighbourhood of the inspected scene. The cameras are usually in fixed positions. In general, inspection takes place only for known objects and in fixed positions. A central processing unit is employed in the extraction, processing and classification of image features. These features need to be known in advance. When the process is time constrained or computational intensive, then dedicated hardware is employed to cope with this problem.

These two applications of image processing – visual inspection and automated assembly – have many things in common and can be treated as a whole as they use similar hardware and employ similar processing algorithms, the most notable difference being that a line-scan camera is used for inspection of components on a conveyor, while a wide angle camera is needed for assembly operations. The most common use of visual inspection is to verify the quality of products and take actions for reporting and correcting these faults and replacing or removing defective parts from the production line. This can be easily seen on a production line that makes biscuits or bottles beer at very high rates. Another possible application of inspection is the measuring of a specific parameter of a product and feed its value back into an earlier stage of the manufacturing process in order to correct its faulty behaviour. Another useful application is to collect data and create some statistics on the efficiency of the manufacturing process, in order to provide the management information that is useful in advance planning.

In automated assembly lines, computer vision can provide feedback to control a robot. In this case, it has to provide detailed information about the positions and orientations of the objects that are the subject of assembly. It also will have to check the conformity of the components before the assembly process starts, so that to prevent faulty behaviour, like trying to fit a screw into a non-existent hole.

In general, an industrial inspection process takes place in following sequence of steps:

1. Image acquisition: In vision everything depends on image acquisition. Any deficiencies of initial images can have serious implications in image analysis and interpretation.
2. Image processing: Once images are acquired, they are prepared for the subsequent operations, by removing noise, or non-uniform lighting. The main operations performed in image processing are outlined in Table 1.
3. Segmentation: This step tries to partition the image into regions of interest that correspond to part or whole objects inside the scene.
4. Feature extraction: Feature extraction is a form of dimensional reduction. It involves reducing the amount of information required to describe a large set of data correctly. Examples of features include size, position, contour measurement and texture detection. These characteristics can be extracted and analysed using statistical, structural, block matching, neural networks, or fuzzy systems. The set of computed features forms the description of the input image.
5. Decision-making: The first step in the decision making process is the reduction of the feature space to an inherent dimensionality of the problem. The reduced feature set is further processed in order to reach a decision. The decision, as well as other types of measurements or features computed, are application dependent. In case of visual inspection, the system has to decide if the result of manufacturing meets the quality standards, by matching the computed features with a known model. The model can be either declarative or procedural. Declarative models consist of constrains of the pixels, regions or detected objects and the relations among them. Procedural models are intrinsically defined in the processes that analyse the image.

Table 1: General operations performed in image processing

Point operations	Global operation	Neighbourhood operation	Geometric operation	Temporal operation
Brightness modification	Histogram equalization	Image smoothing	Display adjustment	Frame-based operations
Contrast enhancement	—	Image sharpening	Image wrapping	—
Negation and thresholding	—	—	Magnification and rotation	—

Source: (Golnabi, 2007)

Industrial Applications

The spectrum of industrial applications of image processing is very generous. The industries that benefit from vision systems range from military, to medicine and from food industry to automotive.

2.1. Food Industry

Vision systems are used in food industry for sorting and for quality inspection. The appearance of bakery products is an important quality attribute, which together with the product flavour significantly influence the purchase potential of the product by consumers. Internal and external appearance attributes contribute to the overall impression of the product's quality. Digital images of chocolate chip cookies were used to evaluate their size, shape, colour and the fraction of the top surface area that was chocolate chip. A number of four fuzzy models were developed in order to be able to predict consumer ratings based on the examined features. Visual inspection of muffins was also performed with the aid of a classification algorithm used for separating dark samples from light ones using graded and ungraded samples. The correct classification of 96% of graded muffins and 79% of ungraded muffins was achieved.

Visual inspection is largely used in quality assessment of meat products. For example image analysis was used in classification of muscle type, breed ad age of beef. The study focused on the analysis of the connective tissue which contains fat and collagen variables. The study extracted a 58 feature rich vector and proved the potential of image analysis for meet characteristics determination. Machine vision has also been employed for analysis of pork loin chop images. Colour image features were extracted from segmented images. Jamieson (2002) uses an X-ray vision system for detecting bones in fish and chicken fillets. The system replies on the different absorption coefficients of the two tissues at low energies, thus allowing the defect to be highlighted. The system was 99% accurate, with a total throughput of 10.000 fillets per hour.

The necessity of responding to the market demand for better products, resulted in a greater need for improving the grading and sorting of vegetables. Computer vision has proved to be a viable solution to meeting these new standards. Colour, size, shape and blemishes are important aspects that have to be taken into account when inspecting vegetables. Study of Fourier based separation technique for shape grading of potatoes, was defined based on harmonics of the transform resulting in 89% accuracy of the vision system.

The exterior look of fruits is of an essential marketing and sale importance. Consumers tend to associate desirable internal quality to external aspects. Computer vision has been successfully dragged in tasks such as variety and shape classification, defect detection and quality grading. Kim (2000) proposed the use of an X-ray imaging system for detection of water imbalances in apples. Eight features were extracted from images of X-ray scanned apples and a neural network based classification processed was employed to categorise the apples. The sugar and acid content in oranges was evaluated by Kondo (2000). Features such as fruit colour, shape and surface roughness were extracted from images. The ratio between real sugar value and the predicted value was 0.84 while acid ratio was 0.83.

Topping type, distribution of ingredients and percentage are key aspects of a successful pizza recipe. Sun (2000) has investigated the use of vision in analysing these features. A region based segmentation was proposed, and proved that it has an accuracy of 90% in analysing topping exposure and evenness. Fuzzy logic was also employed in classification of pizza bases and sauce spread distribution.

Many of the potential contaminants of grain seeds have a quite dark colour, thus thresholding is an obvious approach for detecting them. False alarms, arise from the shadows casted by the grains, thus requiring further recognition procedures. Feature selection methods based on orthogonal transformations were used to differentiate durum wheat from bread wheat with an accuracy ratio of 82%. In the study of Majumdar (2000) a combination of morphology, colour and texture models were employed in the classification of cereal grains. The mean accuracy of the combined model was between 99.7% - 99.8% while testing on different datasets.

Food cans inspection using vision systems developed as early as 1982. Container inspections cover a large spectrum of different quality properties. These include, correct positioning and gluing of labels, base, top or sidewalls defects, fill level Brosnan (2004).

2.2. Automotive

Ubiquitous computing has led to interconnection of cars with the internet and amongst themselves, thus transforming the driver assistance. Driver drowsiness monitoring is a method that uses IR cameras mounted in front of the driver to monitor its behaviour like head and eye leads movement to detect and alert the driver in case of inattentiveness. Driver assistive technologies based on cameras and/or radar sensors are: Adaptive Cruise Control (ACC), Forward Collision Warning (FCW), Intelligent Speed Assistance (ISA), Lane Departure Warning (LDW), Lane Keeping System (LKS), Lane Change Assistance, Night Vision Systems, Parking Assistance and so on. Mobileye developed a system able to detect traffic-signs. Recently, apps have been developed so that smartphones can detect lane markers and assist in navigation by displaying an overlay of graphical directions on top of the GPS maps. In latest models of cars many vendors opted for digital display instead of analogue hand displays. In order to automatically test these digital displays image processing was involved in order to compare the captured images of the display in real time operation with prestored templates Chattopadhyay (2012).

2.3. Medical

Image processing is commonly used in MRI and CT scan processing. Recent advances in temporal and spatial resolution of Multi-Slice Computed Tomography (MSCT) allow studying of arteries in 3D with high accuracy. A semi-automatic method that detects soft plagues in the coronary arteries and quantifies their volume from 3D MSCT datasets was developed in Mas (2008). The method consists of artery centreline extraction using a multi-scale tracking algorithm, a first segmentation of the vessel's lumen in order to fix the centreline detected previously, a final segmentation of the lumen and the wall of the artery, the analysis of the volume along the vessel in order to detect soft plaques and the quantification of the plaques volume.

Some surgical instrument production companies rent the instruments to hospitals. After a while the hospital returns the instrument to the vendor, but they frequently misplace or even forget to return them. The returned instruments need to be sterilized. Image processing is involved in order to monitor whether the instruments are properly placed or not Chaki (2009). Some vendors are interested in proper operation of their instruments. In such chases a video search method that takes as an input an instrument image and returns the timestamps when the instrument has been used in the video Chattopadhyay (2008).

2.4. Inspection of Printed Circuits

Machine vision has been successfully employed in the electronics industry, specifically for inspecting of PCBs. The inspection can take place at three different steps of the manufacturing process.
First, the PCB can be inspected before components are inserted – thus assessing the correctness of the printed interconnection lines. Second, an inspection can take place in order to verify the correctness of the components inserted, and thirdly, the soldering operation can be scrutinized. Faults that can be verified include touching or broken tracks, mismatches between pad positions and the holes on the board. PCB image processing has two main steps: Pre-processing is performed in order to remove noise and neat the way of solder joints tracking. Then the solder joints can be classified into four classes, namely good, excessive solder, insufficient and no solder. Empirical results have shown that efficient classification can be achieved by an optimal feature selection, in which classes do not overlap. It has been shown that histogram-based processing is better performing that feature-based techniques. The problem with such a system is the overlapping of classes thus resulting in an ambiguous classification. To correct this issue, neural networks have been proposed for designing the classifiers that deal with distribution and topology estimation of defects.

2.5. Steel and Wood Inspection

Steel inspection is not a trivial task, as the strip is moving past the observer with speeds that exceed 20m/s. Another issue is the experience need for this kind of work and also the working conditions which involve high temperatures and noise levels. The simplest method requires simple optics and intensity thresholding, although laser devices have been developed in order to ease this process.

A wood inspection solution has been proposed by Bhandarkar (1999). CT image slices are acquired and segmented. Each of the segmented image is analysed and labelled as defect-free or defect-like. Correlation among the CT sequences allows for 3D reconstruction of the log defects. Combining a decision tree with a modular neural network topology, results are far better the using a single neural network for classifying the wood veneer.

2.6. Robotic guidance and control

Autonomous industrial robots require guiding systems. Alignment and adjustment processes also require guiding systems. In general, all robotic actions require visual feedback for position determination in welding or other processes. Vision-Guided Automated guided vehicle (AGV) can be installed with no modifications to the environment or infrastructure. They operate by using cameras to record features along the route, allowing the AGV to replay the route by using the recorded features to navigate. They uses probabilities of occupancy for each point in space to compensate for the uncertainty in the performance of sensors and in the environment. The primary navigation sensors are specially designed stereo cameras.

Conclusions

It can be noticed that a major purpose of inspection systems is to take instant decisions on the compliance of products. Related to this purpose are the often fluid criteria for making such decisions and the need for training the system in such a way, so that the decisions that are made are at least as good as those that would have arisen with human inspectors. In addition, training schemes are valuable in making inspection systems more general and adaptive, particularly with regard to change of product.

We must bear in mind that automated visual inspection falls under the general heading of computer-aided manufacture (CAM), of which computer-aided design (CAD) is part of. Today many manufactured parts can be designed on a computer, visualized on screen, made by computer-controlled machines, and inspected by the very same computer — all without human intervention in handling the parts themselves. There is much sense in this computer integrated manufacture (CIM) concept, since the original design dataset is stored in the computer, and therefore it might as well be used (1) to aid the image analysis process that is needed for inspection and (2) as the actual template by which to judge the quality of the products Davies (2012). After all, there is no need of a separate set of templates for inspection criteria when the specification is already on the computer. However, some augmentation of the original design information to include valid tolerances is necessary before the dataset is sufficient for implementing a complete CIM system.

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