A SYSTEMATIC ALGORITHM DEVELOPMENT FOR IMAGE PROCESSING FEATURE EXTRACTION IN AUTOMATIC VISUAL INSPECTION

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By

G.X. Xing

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ABSTRACT

Image processing techniques applied to modern quality control are described together with the development of feature extraction algorithms for automatic visual inspection.

A real-time image processing hardware system already available in the Department of Production Technology is described and has been tested systematically for establishing an optimal threshold function.

This systematic testing has been concerned with edge strength and system noise information. With the a priori information of system signal and noise, non-linear threshold functions have been established for real time edge detection.

The performance of adaptive thresholding is described and the usefulness of this nonlinear approach is demonstrated from results using machined test samples.

Examination and comparisons of thresholding techniques applied to several edge detection operators are presented.

It is concluded that, the Roberts' operator with a non-linear thresholding function has the advantages of being simple, fast, accurate and cost effective in automatic visual inspection.

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Contents

Summary

This thesis consists of 7 chapters.

Chapter 1 addresses the applications of machine vision technology for quality control. Achieving 100% product quality meeting customers needs, model based automatic visual inspection systems are becoming reality with emerging computer techniques.

Chapter 2 reviews image processing techniques of edge detection, because it is the fundamental processing work in model based automatic inspection.

In chapter 3, a high-speed image processing system used for the experimental work is described, followed by an analysis of feature extraction algorithm improvement requirements. This leads to the formulation of an algorithm development strategy.

Developed software and its edge strength information-noise analysis from systematic plotting of 3-D edge pixel and 2-D contours are presented in chapter 4.

Chapter 5 gives a machine vision thresholding principle which is deduced from Weber's law. Edge processing results of Robert's edge operator with the established non-linear thresholding profiles are presented.

Chapter 6 demonstrates Robert's, Sobel, DIP, RANK and RANGE filter edge detecting performance, and discusses the advantage of thresholding techniques.

The overall conclusions and suggestions for future work are given in chapter 7.

CHAPTER 1

CHAPTER 1 Introduction

1.1 Introduction

Throughout industry today there is a need to improve product and process quality. Good quality will improve productivity and profit.

To achieve tomorrow's quality goal of 100% conformance to requirements, automatic visual inspection and new quality concepts will play a very important part. The real challenge for the development of automatic visual inspection technology is to provide efficient and effective methods to meet customer needs and expectations, at adequate operating speed.

Accurate feature extraction is important in automatic visual inspection, because features are less sensitive to noise in the original gray-scale images and provides data reduction while preserving information required for the inspection. The most important initial feature detection task is that of edge detection, where the goal is to find pixels that lie on the borders between different objects in the scene.

In the past twenty years, many edge detection technologies have been developed [Rob 65; Dav 75; Ros 76; Pra 78; Mar & Hil 79; Mcl et al 84; Hod et al 85; Can 86;]. Because the theory of optimum edge detection algorithms is not well developed, most have limitations for real-time automatic visual inspection applications. This remains the subject of further research.

1.2 Automatic visual inspection in quality control

The benefits that may be realised from quality control include:

1) Improvement in quality of products and services;
2) Increase in the productivity of manufacturing processes;
3) Reduction of manufacturing costs;
4) Determination and improvement of the marketability of products and services;
5) Reduction of "in use" failure;
6) Reduction of consumer prices of products and services;
7) Increase in service life;
8) Improvement in deliveries and availability;
9) Enhancement of the management of an enterprise.

The quality control function has traditionally been performed using manual inspection methods and statistical sampling procedures. Manual inspection is generally a time-consuming task. It requires that parts be removed from the production lines to a separate inspection area. This can cause delays and may become a bottle neck in the production line.

Basic Statistical Quality Control (SQC) philosophy is concerned primarily with the early detection of assignable causes so that product quality may be controlled at the desired level with a minimum of rejects. Table 1 lists the most commonly used statistical tools by category of application.

SQC from its inception has been concerned with economic considerations, and recognises that products must be produced to an adequate quality level at an economical cost. According to J.M. Wiesen [Jur 79] in quality control, advantages of sampling inspection are:

1) Economies due to inspecting only part of the product;
2) Less handling damage during inspection;
3) Fewer inspections, thereby simplifying the recruiting and training problem;
4) Upgrading the inspection job from monotonous piece by piece decisions to lot by lot decisions;
5) Applicability to non-destructive testing, with a quantified level of assurance of lot quality;
6) Rejections by vendors or shop departments of entire lots rather than mere return of the defectives, thereby providing strong motivation for improvement.

The main disadvantages of sampling inspection are:

1) There are risks of accepting "bad" lots and of rejecting "good" lots;
2) There is added planning and documentation;
3) The sample usually provides less information about the product than does 100% inspection.

In reducing time-consuming 100% manual inspection, statistical sampling procedures have been proposed. However, using statistical sampling procedures is an acknowledgement of the risk that some defective parts will slip through. In principle, statistical quality control accepts that something less than 100% quality must be tolerated.

Table 1-1 Summary of Statistical Methods

Application category	Statistical tools
Inspection and test for product acceptance	Lot acceptance sampling By attributes By variables Continuous acceptance sampling Failure distribution analysis
Process control	X and R control charts Precontrol (for variables) P and C charts (for attributes)
Variation research (diagnostic)	Paveto analysis Frequency distribution analysis Process capabilities analysis Multivariate analysis Component swap and Variable swap Measurement accuracy analysis Design of experiments (Taguchi Methods) Analysis of variance Significance testing Evolutionary optimisation Weilbull (and other) failure analysis Scatter design

There are several economic, social, and technological factors at work to modernise the quality control function. The economic factors include the high cost of the inspection process as it is currently performed and the desire to eliminate inspection as a source of costly delay in production.

The social factors include the ever increasing demand by customers for near perfection in the quality of goods, the growing number of expensive product-liability legal cases, and government regulations which require many firms to maintain comprehensive production and quality records.

Another factor in this category is the tendency for some manual inspection tasks to involve subjective judgement on the part of the human inspector. It is considered desirable to try to remove this subjective component from the inspection operation.

The technological factors contributing to modernisation of the visual inspection are the following:

* Extensive automatic visual inspection research and development
* Advances in computer technology
* Faster and more powerful microprocessors
* Cost of computer power continues to drop
* Advances in sensing devices such as charge-coupled devices

All of the above factors are driving the quality inspection function toward 100% automatic inspection. The objectives of automatic visual inspection are:

1. To improve product quality;
2. To increase productivity in the inspection process;
3. To increase productivity and reduce lead times in production.

The strategy for achieving these objectives is basically to automate the inspection process through the application of computers combined with advanced Image Processing technology. Wherever technically possible and economically feasible, inspection should be done on a 100% basis rather than sampling.

100% automatic visual inspections have potential advantages in:

* freeing humans from dull and routine tasks,
* saving human labour costs,
* performing inspection in unfavourable environments,
* reducing demand for highly skilled inspectors,
* analysing statistics on test information and keeping records for management decisions,
* matching high speed production with high speed inspection,
* reducing quality loss,
* ensuring product quality, and in
* increasing profit.

In addition, on-line 100% inspection will introduce opportunities to use the inspection measurements as feedback data to make compensating adjustments in the production process.

There are a number of survey articles and bibliographies published on automatic visual inspection studies of various industrial parts [Chi 82], [Chi 88], [Wal 88].

Chin [Chi 82] has given the following list of automatic visual inspection application categories:

* the inspection of printed circuit patterns;
* the inspection of microcircuit photomasks;
* inspection of integrated circuits on silicon and their alignment for bonding;
* inspection of other electrical and electronic assemblies;
* the inspection of automobile parts;
* visual inspection for metal processing industries;
* visual inspection for fabric processing industries;

The basic components of automatic visual inspection systems are an illumination mechanism, a sensor, an A/D converter, and a processor as illustrated in Figure 1-1.

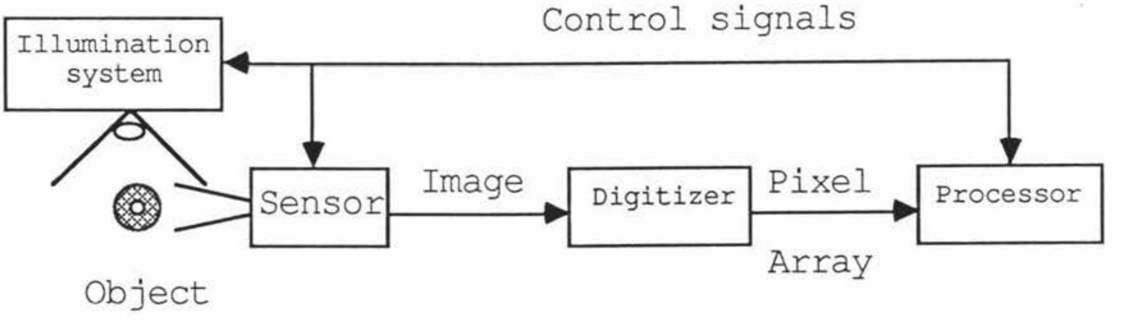

Figure 1-1. Basic components of a automatic visual inspection system [From Ros 85]

The camera-based sensor acquires an image of the object that is to be inspected. The digitizer converts this image into an array of numbers (pixels) representing the brightness values of the image at a grid of points. The processor retains the image for processing to enable the necessary decisions to be made. The processor may also have some degree of control of the sensor, the object, or the environment.

For a particular application it is clear that the design of a machine vision system involves a large number of specialist disciplines related to optics, sensor physics, analog to digital conversion (A/D), direct memory access controller design, algorithm development, computer hardware specification, information display and mechanical control.

1.3 Model based automatic visual inspection

In industry, model-based machine vision inspection algorithms have been in continual development for twenty years. To date, primarily very simple techniques based on 2-D feature models have been applied on real time production lines. However, Chin [Chi 88] has indicated that current model-based systems have weaknesses such as a highl dependence on precision mechanisms and special lighting. More sophisticated techniques need to be developed in order to deal with less structured production environments and to permit more task versatility.

Generally, a model based automatic visual inspection system consists of a modelling phase, a feature extraction phase, and detection phase, as illustrated in Figure 1-2.

Features representing the object are extracted and matched to a pre-defined model. This feature-to-model matching process is the most common technique for detecting defects. It is realised by finding features in the given object that match the model definition of defects. After the detection, a go/no go decision is made to sort the bad parts from the good.

In an automated visual inspection, the first hardware task is to acquire a quality image of the part under inspection. This is often considered to be the most crucial step in the inspection process. The primary objectives are to acquire a quality representation of the object under inspection with the minimum of complexity so as to reduce the subsequent image processing.

Image acquisition involves the design of illumination and optics, and the choice of sensors and their placement. The choice of lighting, optics, and sensors depends largely on the following issues:

1) The type of sensors to be used;
2) The speed of motion of the object;
3) The minimum feature size of the part under examination;
4) The nature of the relevant features for inspection.

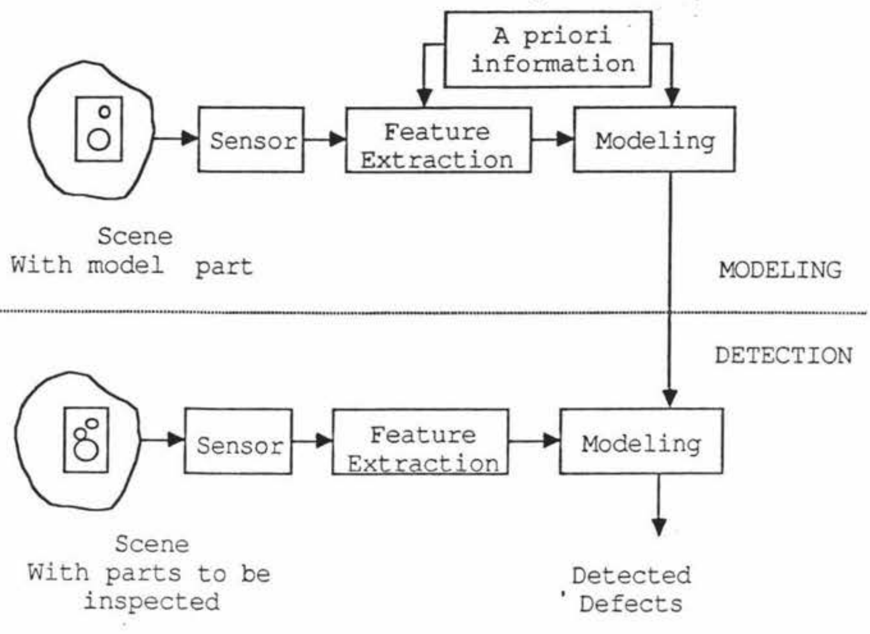

Figure 1-2. Components of a model-based inspection system [From Chi 88]

In some cases, special lighting, such as structured light or polarised light, is employed.

Another basic requirement is the image processor. A common problem in inspection applications is the need to process large sets of predominantly two-dimensional arrays at high speed. Study [Han 86] shown that processing speed of at least one billion operations per second will be required to solve some of the current inspection tasks. This requirement has led to much research in algorithm and special high speed hardware developments [Mcl 84, Nag 87, Elp 87].

High speed algorithms must be realisable in hardware such as general purpose systolic arrays, pipeline architectures, custom VLSI design of specific algorithms, or even more powerful parallel multiple instruction/multiple data architectures to meet the needs of real-time image processing, and image interpretation.

All visual inspection algorithms use "a priori" knowledge. This knowledge is organised into models which provide strategies and standards for the inspection process. Therefore, these systems are referred to as model-based or model-driven systems [Chi 88]. They perform inspection by matching the part under inspection with a set of pre-defined models.

In practice algorithms are developed heuristically by selecting an initial sequence of operations from a large number of possible operations, testing the sequence and then making modifications until satisfactory performance is achieved.

Although research and development in inspection algorithms has increased dramatically over the last twenty years their capability is still very primitive. One reason for this problem is that many manufacturing tasks require sophisticated visual interpretation, yet demand low cost, high speed, accuracy, and flexibility.

1.4 Edge processing in inspection

The main purpose of model based automatic visual inspection is the extraction of the most significant features such as edges, then matching these features with a set of pre-defined models to detect defects.

Accurate feature extraction is important in automatic visual inspection, because it will reduce data and noise while preserving the information required for the inspection.

In edge detection, the goal is to find pixels that lie on the borders between different objects in the scene [Ros 88]. In order to develop more realistic feature extraction algorithms to achieve high speed processing, it is necessary to examine current edge detection techniques.

Edge extractors can be divided into two broad categories. One is based on computation which includes local gradient, digital image filtering processing etc. Other approaches are knowledge based such as adaptive or median filtering techniques.

Traditionally, an "edge" is the first step discontinuity that lies between two regions of uniform but different light intensity. In reality natural image regions are rarely of uniform intensity and the step function must be smoothed into a ramp or similar function.

Extensive research has been devoted to the very earliest stage of vision; extracting discontinuities from the pixel array. When the images are entirely noise free this is simple, but traditional local edge detection methods are very sensitive to additive noise.