Image Acquisition and Processing Techniques for Industrial Inspection

B. G. Batchelor & G. E. Foot

Abstract
The concepts and design of automated visual inspection systems are described. The multidisciplinary, systems-orientated nature of the subject is emphasised; an industrial inspection system inevitably incorporates elements of mechanical handling, lighting, optics, sensors, as well as electronic and software-based image processing. Image acquisition, for example, is regarded as being of equal importance to image processing. There is a detailed discussion of illumination & viewing techniques. Different types of image sensor are compared. Image processing systems may incorporate slow, low-cost, flexible software, or fast, fixed-function, and expensive hardware. Their relative advantages are reviewed. A number of practical applications of automated visual inspection techniques are then discussed.

1. Introduction
The importance of inspection in manufacturing is well understood, since quality and reliability are both prime factors influencing customer choice. Rapid advances in production techniques have increased the need for improved inspection methods. In particular, there is a requirement for increased speed of inspection, to match that of fast, modern production processes. The implicit inspection provided by manual production and assembly are no longer present when full automation is achieved. The quality assurance engineer has many inspection and measurement tools at his disposal, which have been developed to a high level of sophistication over many years. One of these is provided by Automated Visual Inspection (AVI). It offers an attractive, relatively new approach to improving product quality, although the technology has not yet had the benefit of being refined during a long period of evolutionary development. The potential benefits of this young area of industrial automation will be discussed in this article, as will some of the techniques and applications.

Figure 1 shows the organisation of a typical AVI system. Individual AVI installations may differ from this in detail, but this block diagram serves as a useful model on which to base our discussion. Notice that an AVI system almost invariably contains elements of mechanical handling, lighting, optics, electronics (analogue and digital systems), software and algorithms. All of these must be carefully selected and integrated so that they operate together harmoniously. These two sentences have been highlighted, to emphasise the fact that they represent the most important single statement in this article. For appropriate applications, a properly designed AVI system offers several advantages over other inspection techniques and provides:
(a) greater reliability than human inspectors who are prone to producing errors, due to fatigue, boredom, distraction, hunger, illness, etc.
(b) greater versatility than all forms of mechanical (contact) sensing and gauging. (It may even

---

1 Department of Electrical & Electronic Engineering, University of Wales Institute of Science & Technology, Cathays Park, Cardiff, CF1 3XE, Wales, U.K.

2 Department of Electrical & Electronic Engineering, Polytechnic of Wales, Pontypridd, Mid Glamorgan, CF37 1DL, Wales, U.K.

3 Automated visual inspection was first proposed as early as the 1930s but there was no understanding, at that time, of the need for powerful computing techniques, which in any case did not exist.
be possible to do certain things using AVI that cannot be achieved in any other way.)
(c) higher speed both human and mechanical inspection systems
(d) reduced unit inspection costs.
The principal benefits of optical sensing arise from the fact that it offers a means of non-contact inspection, which is inherently safe, clean and gentle in its treatment of the artifacts being examined. Apart from the human-eye, there is, for example, no single alternative means of inspecting a red-hot steel slab, a cream cake, an aerosol spray, a free-falling 'gob' of molten glass, a dollop of unbaked dough or clay, a complete motor vehicle or a micro-electronic circuit. However, it must be emphasised that, to date, AVI has not been able to approach the great potential that was anticipated for it in the 1970s. By 1980, it was realised that the promise was far greater than the achievement. In order to appreciate why, it is necessary to understand that AVI inevitably demands high computation rates, which could not be provided in a cost-effective manner, until very recently. Even today, there are numerous applications that we know how to solve, but for which we cannot provide fast, effective, low-cost hardware. This article develops this theme, by showing that, in a number of laboratory studies, the feasibility of a wide variety of important inspection tasks has been established, even though this work has not yet resulted in the construction of factory-floor inspection systems. In doing so, some of the numerous image acquisition and processing techniques that have been proposed will be encountered. We shall also consider some of the image processing systems that are likely to influence the development of AVI and allow it to reach more areas of manufacturing within the next few years.

2. The Need for Improved Inspection Techniques
The need for improved inspection techniques will be demonstrated by listing a number of outstanding and important industrial applications. Others are described in Section 6. This informal approach is not able, nor is it intended, to demonstrate that there is a viable market for AVI systems, but instead that the potential gains for certain areas of manufacturing industry from the use of this technology are very great indeed. The authors are of the opinion that industrial managers often grossly underestimate the potential value of using AVI. Caution in using a new and "unknown" technology is a major cause of investment inertia. Lack of understanding of the potential of opto-electronic sensing, accompanied by a lack of imagination, also leads to reticence in installing AVI systems. The following list is merely a small subset of the applications that have been studied to date.
(i) Inspecting glassware for a wide variety of faults, including cracks, loose glass, gross shape deformations, and an unpleasant fault known as a spike. The last of these is like a stalagmite of glass, protruding upwards inside the jar or bottle. It can easily become broken during filling, which may leave a nasty "cocktail" for a drinker to swallow. Another fault, this time in drinking glasses is discussed in Section 6.6.
(ii) Detecting flaws on red-hot steel slabs, thereby saving the cost of reheating. This offers a truly enormous potential pay-off: 1% of the fuel bill in the U.S.A. [1]
(iii) Detecting foreign bodies in food-stuffs, toiletries and pharmaceuticals. (There are obvious dangers in this type of fault.)
(iv) Finding scratches on the surfaces of the bores of hydraulic cylinders. (Failure of such a component in the braking system of a car might result in the death of passengers or other innocent people.)
(v) Locating wires protruding from the cap an electric light bulb. One of the authors (BGB) has experience of three companies who recognise this problem as being serious, since electrocution can result from the use of a such a lamp. [2] Also see Section 6.1.
(vi) Detecting foreign bodies, fingerprints and minute scratches and pits on magnetic recording media for computers. (These faults can lead to data drop-out, or worse to a head crash.)
(vii) Inspecting printed circuit boards, both with and without components. (The high cost of building circuit boards with faults in them is the major justification for this application.)
(vii) Guiding robotic devices to pick objects from a conveyor belt, to load machines. See Section 6.5.