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SYSTEM ENGINEERING ISSUES IN INDUSTRIAL INSPECTION

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Machine intelligence is not an exercise in philosophy but an engineering project. [1]

The design of industrial inspection systems, requires a broad spectrum of techniques and disciplines. These include electronic engineering (hardware and software design), engineering mathematics, physics (optics and lighting) and mechanical engineering (since industrial vision systems deal with a mainly mechanical world) [2]. However, many industrial vision systems continue to be designed from a purely software engineering perspective, without consideration for any of the other system disciplines. While it is acknowledged that the software engineering task in industrial inspection is a critical one, the other system elements are neglected at our peril. No single discipline should be emphasised at the expense of the others. Lately, a number of researchers [3, 4] have argued for the design of vision systems to be firmly placed back into a systems engineering framework. This arises from the belief that an inadequate amount of vision research deals with the genuine design and systems problems involved in the implementation of industrial vision systems. The aim of this paper is to discuss the current state of industrial inspection, as seen from a systems engineering perspective.

The Importance of Context

During the development of industrial inspection systems over the last 30 years there has been two main approaches [2]. One approach that researchers took was the development of general purpose industrial inspection systems. These systems mainly concentrated on the software aspect of the vision task, and due to the generality of such systems, vision integrators were faced with a wide and varied range of image processing, and to a lesser extent, image analysis techniques. The main challenge facing system designers is to reduce the complexity of the system, to enable it to carry out the required inspection functions, under the tight budgetary and operating conditions required by industry. The success of such systems in the manufacturing environment have been limited, since they require a significant amount of work and reprogramming to get them to perform a practical vision task.

The second approach is based on generating turn-key vision systems which provide total solutions to a given industrial task. These systems have the advantage of begin tuned to a specific application. They tackle the problem rather than trying to fit the task to a collection of software procedures which are looking for an application. However, the second approach will only work effectively if the designer takes into account the context of the industrial application. [5]

So, what is meant by the *context* of a industrial inspection system ? The dictionary definition of “context” is given as *"conditions and circumstances of an event"*. For example, one can recognise and understand abstract words in the context of a sentence structure with less difficulty when compared to viewing/hearing such words in isolation [6]. This highlights the strength and importance of context in trying to make sense of the world around us. Likewise, in the successful development of industrial inspection systems, it is necessary to view the problem in its entirety. All possible considerations, electronic, optical and mechanical must be considered. This is not an easy task, and many vision system designers feel uncomfortable dealing with system issues, which are often outside their own area of expertise.

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The complexity of an industrial inspection application is largely a reflection of the complexity of the environment in which it finds itself. Therefore, a successful vision application requires a total systems approach and requires a range of engineering and practical skills to deal with the complex industrial environment. By adopting a systems approach, the maximum use is made of problem-specific "contextual" information, derived, for example, from the nature of the product being handled, the process used to manufacture it and the special features of the manufacturing environment. Doing this, it is often found that the complexity of the application can be reduced.

In the modern manufacturing environment, economy of *scope* is becoming as important as economy of *scale*. Companies must be able to produce a variety of products using a flexible manufacturing system, while maintaining a very high level of quality. There is a need to extend the role of machine vision beyond that of inspection, to become the key controlling element in a closed loop process. Such integration will allow flexible control of the production line, using defect information to locate fault sources and allowing automatic feedback for adjustment and correction, as well as monitoring the overall efficiency.

Researchers and engineers must also be open to the idea that vision may not be the appropriate or ideal approach for the task at hand. Some tasks that the end user may see as being a suitable application industrial inspection, may in fact be better served by using other engineering approaches, such as the use of mechanical sensors, optical and electronic transducers. Some of the unsuccessful vision applications of the past have been caused by applying vision technology for its own sake. For industrial inspection to become generally accepted by the manufacturing community, it must concentrate on tackling the industrial problems, rather than try to employ a given technology for its own sake. There are considerable benefits in adhering to the Japanese philosophy of restricting the tasks to suit the capabilities of the equipment.

Industrial Examples

The case studies discussed in this section illustrate the complexities of designing and building an industrial vision system and emphasise how detailed knowledge of the application context can simplify the vision system design. The purpose of including these case studies here is to explain the development of industrial vision systems while concentrating on the systems engineering approach to the vision problem, rather than the image analysis and processing routines.

A. Inspecting for colour mis-registration

It is often surprising the extent to which a product’s design can be constrained to suit the limitations of the vision system, without adversely affecting the product’s functionality, aesthetics or the ability to manufacture the product. Although it can be argued that this imposes intolerable constraints on the product design, these restrictions need not be any more rigid than those imposed by good design for 'manufacturability'. For example, in this case study the vision system designers were faced with the task of checking for colour mis-registration on high quality printed cartons. In this case, the product was slightly modified, to simplify the image analysis task.

The manual method of inspecting for colour mis-registration requires the examination of the printed sheets, after they have been cut into individual cartons, folded and passed through the gluing stage. Gross registration errors are obvious to the inspector after an initial glance at the carton, whereas slight registration errors are found by viewing the printer’s registration mark. (This mark is printed on a part of the carton that is hidden from consumer, once the carton is assembled. See Fig 1.) Due to the highly automated nature of the printing process, there are few gross registration errors. In practice, the majority of errors are due to slight slippages in the printing process. These slight registration errors are difficult to find and classify manually.

Fig 1 shows an example of a manual registration mark, initially printed in black on a white background As each new colour is applied to the carton, a new registration mark, of the same design but in the new colour, is overlaid on the original printed mark. Therefore, if all the colours are registered correctly, they produce a single well defined registration mark. However, if any type of mis-registration occurs, the registration mark for that colour appears shifted with respect to the black reference mark. The inspection of the original design for the registration mark (Fig 1) was difficult for the machine vision system to handle. The registration mark is not only difficult to describe, but if mis-registration occurs the image becomes more complex and hence more difficult for a machine vision system to analyse.

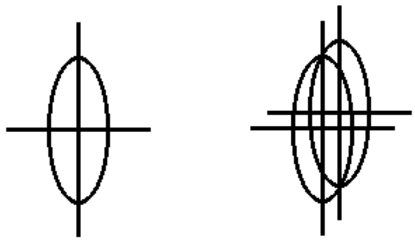

Fig 1. Registration symbol for manual inspection. The figure on the left indicates correct registration. The figure on the right indicates incorrect registration of two overlaid registration marks.

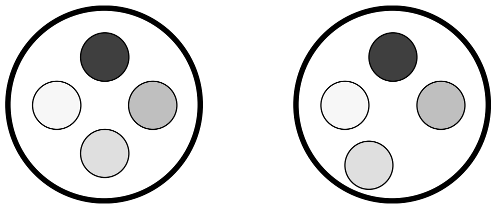

Fig 2. Modified colour registration symbol. The figure on the left indicates correct registration. The figure on the right indicates incorrect registration of the lower inner disk.

In this instance, the product modification simply involved the redesign of the registration mark (Fig 2). This new registration mark consists of an outer black circle which contains a number of solid coloured disks, one for each of the subtractive primaries (magenta, yellow and cyan), and a fourth solid disk, representing the extra solid colour to be printed (green in this application). This is printed on a white background. The black ring is laid down first and acts as the registration reference colour. As each colour is applied by the printing process, a solid disk of that colour is also printed inside the black reference ring. The offset of each of these disks, measured from the centre of the black ring, gives a measure of the position for that colour imprint with reference to black.

The ability to modify the product to suit the vision system's capabilities and strengths, highlights the benefits of holding detailed discussions with the end user during the feasibility study. If the end user is involved from the beginning of the design process, the designer may be fortunate to find that the customer is willing to consider changes in product presentation which will simplify the vision task. This is more likely, of course, if it can be shown that system costs can be reduced by doing so. The use of this custom registration mark, developed in conjunction with the end user, transformed a potentially difficult and expensive vision task into a much simpler one.

B. Can end inspection

This case study describes the high speed inspection of pull tab easy open metal can ends. The can ends are produced from either aluminium or steel metal sheets. These sheets are printed with customer information on one side, while the other side is lacquered to prevent the bare metal coming in contact with the food stuffs or beverage contained in the can. These sheets are then placed in a punch press which produces the formed can ends. Once pressed, the lacquer side of the can end is facing up and it is while they are in this orientation that the inspection process is carried out.

The outer edges of the can are curled upwards into a concave shape during the pressing process (this region is referred to as the curl region, see Fig 3). The can ends are then passed through a solvent based can end lining system which places the liner compound material around the outside edge of the can end, just inside the curl region. The output of the liner stage feeds two conveyor lanes, each of which pass under one of the vision system inspection heads. The vision system controls the two inspection heads, each comprising of a single CCD camera and a xenon strobe ring light unit (a 256x256 pixel resolution CCD camera (64 grey levels)). Each inspection head enclosure is pressurised with filtered compressed air to prevent dust accumulation on the optics and light unit. At this stage the can ends are inspected for defects.

The inspection system detects and removes any can ends defects. Defects include voids in the lining compound, clipped curls, defects in the can end due to scrap in the punch press die, oil contamination and compound splash on the can end centre panel. Complications are introduced by variations in the material types, surface finish and colour, lacquers and compound consistency.

It is interesting to note the kind of overall system engineering problems that can begin to occur. For example, conflicts between the standard choice of conveyor belt and the needs of the vision station. Since the can ends can be either steel or aluminium, two types of conveyor holding mechanisms are used (magnetic and a vacuum suction). The vacuum suction method causes most problems because it necessitated the use of suction holes on the conveyor belt (which is specified as matt black in order to cut down the belt reflections). These suction holes appear in the field of view as white rings (due to the belts white backing) which, when placed near the can ends, confuse the vision system's automated centring facility and thus produce false rejects. This problem was overcome by a change in the conveyor belt specification. For this reason it is advisable that during the development of an industrial vision system the vision integrator should keep total control of the inspection section of the production line therefore avoiding the unfortunate situation of retrofitting the vision system to a section of production line over which they have no control. Of course, this may not always be possible.

The key to the success of this application lay in the custom lighting design which was necessary to illuminate the regions of interest on the complex surface to be inspected. The lighting unit has two main functions. Firstly it must illuminate the total lacquered and compound surface of the can end, which consists of flat, concave and protruding surfaces. Secondly the lighting system must be designed in such a way as to be easy to maintain. This was an important consideration in the overall lighting design due to the fact the xenon bulbs used had a short lifetime. Therefore it had to be possible for the line operator to replace the bulb without upsetting the critical optical path of the imaging system. Initially a custom built LED lighting array, was strobed in order to freeze the can end as it appeared in the cameras field of view. This design was later replaced by the more robust xenon strobe ring light unit shown in Fig 3.

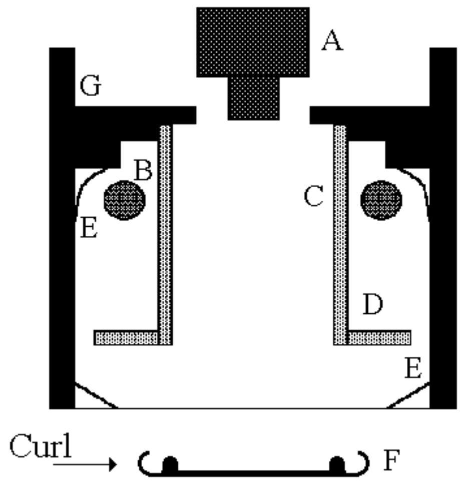

Fig 3. Cross-section of the can end xenon strobe ring light unit. A. CCD camera, B. Xenon strobe ring light, C. Diffuse cylinder, D. Diffuse plate, E. Angled reflectors, F. Can end under view with the concave curl region highlighted and G. Support casing.

The main components of the lighting unit consisted of a xenon strobe ring light surrounding a diffuse plastic cylinder. This cylinder is used to channel diffuse light towards the can ends centre panel. The plastic diffuse plate, located at the base of the diffuse cylinder, is used to place diffuse light on the ridge and compound regions of the can end. This plate was mounted so that it could be easily removed from the rest of the lighting unit, without affecting the lighting configuration. Due to the semi-viscous nature of the liner compound, there was a possibility of compound (which is a sticky grey material) splashing onto the lower end (diffuse plate) of the lighting unit. Hence the requirement for the diffuse plate to be removable. These compound splashes tend to be rare but large in nature, therefore forcing a total shut down of the can end line in order to clean the lining feeder prior to a resumption of the lining operation, thus giving ample time for the diffuse plate to be checked and replaced if necessary.

Two circular mirrors were placed concentric with the xenon ring light. The top mirror, which is slightly curved, directs light into the compound channel regions. The lower mirrored surface is used to reflect light onto the diffuse plate and hence illuminate the curl region with diffuse light. The lower mirror was also designed to be removable in case of bad compound splash. The whole lighting system is enclosed in a metal support casing for protection and stability. The imaging system was protected, from the inspected can ends, by placing an anti-jamming bar before the inspection heads. Any jamming of the metal can ends underneath the inspection heads would seriously damage the imaging system.

Intelligent Vision

The majority of industrial inspection applications are concerned with simple, well defined, mass produced goods. Nevertheless this only forms a small proportion of the overall manufacturing industry; the majority of manufactured goods are made in batches of 50 or less. Consequently, there is a need to make vision systems more flexible to cope with the different demands of small batch manufacture, particularly the ability to have a fast application turnaround. This points towards the need to develop a new generation of 'intelligent' (or adaptive) industrial vision systems. Intelligence is needed

- to interpret the description of the object to be recognised
- to interpret a complex visual scene
- to plan actions following the recognition process.

It is clear from even simple situations that intelligence and vision are intrinsically dependent upon each other. Intelligence needs vision to supply it with sensory data. Vision needs intelligence to resolve ambiguities in visual scenes and to make high-level judgements about what a complex scene contains. To advance from the current generation of industrial inspection systems to a new, more flexible family requires addressing a number of key issues:

- Development of adaptive (intelligent) industrial inspection systems.
- Application of a systems engineering approach to industrial vision tasks.
- Maximise the use of contextual information available from the product, process and application environment.
- The production of standard solutions to industrial problems.
- Tackling of sub-goals.
- Widening the application base.
- The use of vision in a process and quality control role.
- Performance characterisation tools.
- Ability to deal with unclear or missing information.
- Systematic testing and repeatable experimental results.
- Generic tools to deal with common analysis features such as shape, size, colour and texture.
- Investigation of algorithmic and heuristic procedures.
- Flexible, user friendly interfaces.
- Broader education of the systems issues.

Industrial inspection can only progress and become fully accepted in manufacturing industry, if is employs advances in vision research in a sensible way [4].

Proverbs, Opinions And Folklore

Finally, I would like to point the reader towards some of the proverbs, opinions and folklore that surround industrial inspection. This is a list of observations, comments, suggestions, etc. based on past experience. By its very nature, this list is dynamic and additions to it are always welcome (contact *whelanp@eeng.dcu.ie*). While this is offered in a light-hearted manner, it encapsulates some important lessons, which are unfortunately not universally acknowledged. Subject headings include:

- General.
- Systems.
- Customer.
- Financial.
- System Specification.
- Choosing Inspection System Design Samples.
- Vision Company.
- Alternative Solutions.
- Mechanical Handling.
- Lighting and Optics.
- Image Resolution.
- Related Disciplines.
- Environmental Protection.
- Proving and Working with the System in the Factory.

A full listing is provided on the Web [7].

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