SPIE
Milestone Series

Selected Papers on Industrial Machine Vision Systems

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and

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Milestone Series:

Selected Papers on Industrial Machine Vision Systems

1. Systems Issues

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Industrial Vision Systems

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What is machine vision? Machine vision is an umbrella term used to describe many different types of vision systems, but in general, machine vision systems are used in the automated processing, analysis and understanding of images in an industrial environment. A more formal definition is given by the Automated Vision Association thus

"The use of devices for optical, non-contact sensing to automatically receive and interpret an image of a real scene in order to obtain information and/or control machines or processes." [AVA85]

The design of industrial vision systems requires a broad spectrum of techniques and disciplines (Paper #6). These include electronic engineering (hardware and software design), mathematics, physics (optics and lighting) and mechanical engineering (since industrial vision systems deal with a mainly mechanical world). However, despite this, 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 machine vision 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 [Paper #45] 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 [Sim81] involved in the implementation of industrial vision systems.

The current growth of machine vision applications in manufacturing is due, in large part, to the falling cost of computing power. This has led to a proliferation of vision and has enabled the development of cheaper systems of comparable power. This, in turn, has enabled medium-sized manufacturing companies to consider, for the first time, the option of using machine vision to implement their inspection tasks.

The use of automated visual inspection systems allow manufacturers to keep control of product quality, thus maintaining their competitive position. Machine vision has also been used to ensure greater safety and reliability of the product, bearing in mind that the better the general level of quality the more difficult it is to find the occasional defect. Vision systems have given companies greater flexibility in control of the manufacturing process. The whole area of flexible automation is an important and growing one, and machine vision will be an essential element in future flexible automation systems. There are also situations, such as inspection in a hostile environment, where on-line inspection could not be carried out until the introduction of machine vision. The fact that inspection in such an environment is possible can lead to the development of a new production process [Hol84]

Many companies now realise that machine vision will form an integral part of a long-term automation strategy, bearing in mind the importance of quality in today's manufacturing process. This, combined with the legal implications of selling defective products, highlights the case for using machine vision in automated inspection. A similar argument applies to the application of vision to robotics and automated assembly.

No machine vision system today, or in planned the foreseeable future, can approach the interpretative powers of human a human being. However, current machine vision systems are better than people at some quantitative tasks, such as making quantifiable measurements under tightly controlled conditions. These properties enable machine vision systems to out-perform people, in certain limited circumstances. Industrial vision systems can generally inspect simple, well-defined mass-produced products at very high speeds, whereas humans have considerable difficulty making consistent inspection judgments in these circumstances. Machine vision systems exist that can handle speeds as high as 3,000 parts per minute, which is well beyond human ability. In fact, experiments on typical industrial inspection tasks have shown that, at best, a human operator can only expect to be 70-80% efficient under normal operating conditions [Mal89]. Depending on the technology used, a machine vision system would be expected to achieve a substantially higher inspection efficiency. It can theoretically do this for 24 hours/day, 7 days /week, 52 weeks/year. Machine vision can be particularly useful in detecting gradual changes in continuous processes (e.g. tracking gradual colour variations in the web materials). Gradual changes in colour are most unlikely to be detected by a person.

Currently the main application areas for industrial vision systems occur in automated inspection and measurement [Whe91] and, to a lesser extent, robotic vision. Automated visual inspection and measurement devices have, in the past, tended to develop in advance of robot vision systems. In fact, quality control related applications, such as inspection, gauging and recognition, currently account for well over half of the machine vision market. This has been achieved, in many cases, by retrofitting inspection systems onto existing production lines. There is a large capital investment involved in developing a completely new robotic work cell,. Moreover, the extra uncertainty and risks involved in integrating two new and complex technologies makes robot vision system development lag behind that of inspection devices. The difficulties involved in controlling flexible visually guided robots have also limited the development. [Bro83].

Machine vision inspection systems now appear in every major industrial sector, including such areas as electronics (PCB inspection, automatic component recognition), car manufacturing (inspection of car bodies for dents, dimensional checking), food (inspection and grading of fruit and vegetables, inspection of food containers), and the medical industries (tablet quality control, detection of missing items in pharmaceutical packets). (Paper #2)

Machine vision system for industry first received serious attention in the mid-1970s (Paper #1), although the proposal that video system be used for industrial inspection was first made in the 1930s. Throughout the early 1980s, the subject developed slowly, with a steady contribution being made by the academic research community, but with only limited industrial interest being shown. It seemed in the mid-1980s that there would be a major boost to progress with serious interest being shown in vision systems by the major automobile manufacturers. Then, came a period of serious disillusionment in the U.S.A., with a large number of small vision companies failing to survive. In the late 1980s and early 1990s, interest has grown markedly, due largely to significant progress being made in making fast image processing hardware. Throughout this period, academic workers have been steadily proving feasibility in a very wide range of products, representing all of the major branches of manufacturing industry.

Indusrial image processing systems, which necessarily form part of a vision system, have developed very considerable progress in the last 5 years. In addition, there have been major advances in other component technologies, concerned with image sensors, specialised lighting units, lenses and advisor programs, which guide a vision engineer through theinitial stages of the design process.

The Milestone series editor, Dr. Brian Thompson, first suggested to BGB in 1989 (?) that a volume in the Milestone Series would be a welcome addition to SPIE’s catalogue. His initial reaction was favourable but, upon reflection, he began to doubt whether there was a solid theoretical basis for such a venture. It seemed to him that this subject was developing very rapidly and that, unlike a pure science, it did not have a corpus of fundamental knowledge or techniques. PFW pointed out that a Milestone volume does not necessarily have to be regarded as a collection of articles that will be held in awe by researchers in perpetuity. He argued that it should instead be thought of as being a convenient gathering together of previously published material which when taken formulate a message that is important to convey: *designing machine vision devices is a systems engineering activity*.

After all of this uncertainty, we now perceive that there is a need for a collection of papers that will

(a) enable machine vision engineers and researchers to gain a broad view of the current state of the technology.
(b) distinguish the work that we are doing from the work in Computer Vision and Image Processing.
(c) act as a guide to past successes, by providing inspiration and inspiring faith in the technology, when tacking difficult applications.

We have deliberately avoided the tempation of trying to collect together the “best” 50 papers on machine vision. Instead we have attempted to formulate a standard core set of knowledge and delineate what attitudes we think are desirable when approaching the design / selection of a visions sytem.

Inevitably, the selection of technical articles included in a collection such as this reflects the personal approach of the editors to the subject. We have made our choice on the basis that, *when they are considered together*, they formulate a single integrated, approach to vision system design, which of course, reflects our thoughts and experience. As a result, many excellect papers on this fascinating subject have not been included. In particular, we have not included papers on image processing techniques, because they are well documented elsewhere. [Che85, Fis87] We have deliberately set out to define a systems approach to machine vision. This theme recurs over and again in the following pages. We cannot conceive of any approach to vision system design that does not take as its basis the fact that the device has to work in a hostile facory environment where neglect is the best that can be expected and abuse is commonplace.

We conclude this brief introduction by listing a series of thoughts about the subject. These have been developed and refined over many years of experience in the laboratory, factory, meeting room. This will, we hope, prompt discussion. To do this , we may generate some controversy but this is a risk worth taking, for the sake of advancing a subject that has a potentially huge contribution to make, not just to manufacturing industry but through it, to human society as a whole. It is in everybody's interest to make sure that our food, drugs, cars, aeroplanes, electrical goods, etc. are all of the highest possible quality.

Machine Vision Systems for Industry: Proverbs, Opinions and Folklore

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Preamble

The following is a list of observations, comments, suggestions, etc. based upon our direct and our colleagues' experiences. It is offered in a light-hearted manner but encapsulates some important lessons that we have learned but which are unfortunately not universally acknowledged. We hope it is will bring enlightenment and promote discussion among our colleagues. By its very nature, this list is dymanic and additons to it are always welcome.

General

o There is more to machine vision than meets the eye.

A machine vision system does not see things as the human eye does.

o An eye is not a camera. A brain is not a computer.

Machine vision systems should not necessarily be modelled on, or intended to emulate human vision.

o No vision system should be required to answer the general question "What is this?"

It is better for vision systems to answer more specific questions, such as "Is this widget well made?" Verification (i.e. checking that the widget is well made) is better than recognition, where few or no a priori *assumptions are made.*

o Intelligence _ Computing power

Making the computer more powerful does not necessarily make the system smarter.

o Optimal solutions do not always exist.

If they do exist, optimal solutions may be too complex, or impossible to find. We should therefore be prepared to search for and accept satisfactory solutions, rather than optimal ones.

o Use a standard solution to a vision problem but only if it is sensible to do so.

Wherever possible we should provide standard solutions to industrial problems, since this helps to broaden the application base.

o Avoid the application of machine vision techniques for their own sake.

It is vanity on the part of the vision engineer to do so. There are plenty of other methods of solution available. Most of them are cheaper than vision.

o Defect prevention is better than cure.

We should consider using vision in closed loop feedback control of the manufacturing process.

o Do not rely on second-hand information about the manufacturing process and environment.

The vision engineer should always see the manufacturing process for himself. If the customer is unwilling to let the vision engineer into the factory, it may be necessary to abandon the application.

o Vision systems need not be fully automatic.

While it is more usual to use a fully automatic vision system, it can be used instead to enhance images for subsequent human analysis.

Systems

o No system should be more complicated than it need be.

This is a reformulation of Occam's Razor, which in its original form is "Entia non multiplicanda sunt." In its English translation, excessive complication is attributed to mere vanity. In colloquial use, this is often referred to as the KISS principle. (Keep it simple, Stupid.) Simple systems are almost always the best in practice.

o All parts of a properly designed machine vision system bear an equal strain.

Of course, it is impossible to measure strain in any formal sense. The point is that no part of a vision system should be made more complicated because a sloppy attitude has been adopted during the design of other parts. A particularly common error is the tendency to concentrate on the image processing, to the detriment of the image acquisition (i.e. pose of the object being inspected, lighting, optics and sensor).

o If it matters that we use the Sobel edge detector rather than the Roberts operator, then there is something fundamentally wrong, probably the lighting.

This remark is not about the relative merits of the various edge detection operators but is a statement about the need for a broader "systems" approach. A common error is to pay much more attention to the image processing process but ignore the fact that the image contrast is low because the lighting sub-system is poorly designed.

- o The following equation is always true

  Vision system $\neq$ PC + Framegrabber + Software+camera

  To many people, these are the only components needed to build a vision system. However, this neglects many important issues: lighting, optics, camera, algorithms, systems integration, ergonomics and standard industrial inspection practice.

- o Problem contraints allow the vision engineer to simplify the design.

  By taking systems issues into account, it may well be possible to design a simpler, faster, cheaper and more robust system.

- o Vision systems can use the same aids as people to reduce task complexity.

  For example, special optical/lighting techniques, X-rays, fluoroscopy, multi-spectral imaging, specialised sample preparation can all be used.

Customer

- o Whatever software and hardware that a machine vision system uses, the customer will want it to to be different, so don't tell him/her.

  Many customer companies have a policy of using certain types of computer hardware / software, which will often conflict with the vision system. It is wise to regard the vision system as a closed box.

- o The customer must not be allowed to tinker with the system after it is installed.

  The customer should be dissuaded from making internal adjustments to the system, since this requires rare and specialised skills (lighting, optics, camera, algorithms, systems integration)

- o The customer's company just does not make defective widgets; the vision system is simple intended "to improve product quality".

  Companies are often sensitive about the way that quality (or lack of it) in their products is discussed. This must be borne in mind when designing a vision system and particularly when reporting developments at conferences, in publications, etc.

- o Everybody (including the customer) thinks he/she is an expert on vision and will tell the vision engineer how to design the machine.

  This is, regretably, one of the great truths. As a result, everybody will feel it is their right and duty to tell the vision enginer how to do his/her job. In many instances, prototyping tools need to be used for the specific purpose of convincing the customer that his/her intuitive approach just does not work reliably.

- o The widgets that were provided for the feasibility study were specially cleaned/chosen by the customer for the project.

  Beware of the pernicious habit of some customers who deliberately, or inadvertently, select good quality products to show the vision company, rather than providing a more representative sample.

- o Customer education is an integral part of vision system design

  A well educated customer can help to reduce the project cost and may well help to reach a better system design.

- o A little knowledge is a dangerous thing.

  The customer will suggest many changes to the system design if h/she is ignorant of the sublities which led to the present design. It is best to tell the customer all or nothing. For example, the vision engineer should not tell the customer that the system uses a camera costing $5000, because the latter will know of a camera that costs only $100 but will not appreciate the benefits of the more expensive device.

Financial

- o The vision system must pay for itself in 6 months.

  The vision engineer must be prepared to argue against the simple-minded attitude which attempts to judge the value of a vision system solely on financial grounds. When a company buys a vision system, it is investing in the improvement of the quality/safety of its products.

- o Component cost is not the same thing as system cost

  By purchasing one relatively expensive component, it may be possible make the overall system cheaper, faster and more reliable.

- o Only ten percent of the cost of installing a vision system is directly attributable to the requirements of image formation, acquisition and processing.

  The remaining ninety percent of the project cost is due to making the system work properly in the factory.

System Specification

- o The specification of the vision system is not what the customer wants.

  Do not try to take short cuts in the initial dialogue. The vision engineer should be prepared to spend a considerable amount of tiime finding what the customer really wants.

- o No machine vision system can solve the problem that the customer forgot to mention when placing the order.

Undertake a proper design study for each type of product.

- o The specification of a vision system should indicate its functionality and performance.
  It should not be used merely as a marketing tool.

- o Beware when the customer says "By the way! We would like to be able to inspect these objects as well."
  We repeat the point just made above: undertake a proper design study for each type of product.

- o The customer said his widgets were made of brass. He did not think to state that they are always painted blue and oily.
  To the vision engineer, the surface finish is more important than the underlying material. This contrasts sharply with the customer who often regards surface finish as being of mere cosmetic value.

Vision Company

- o A sales-person who says that his/her company's vision system can operate in uncontrolled lighting is lying.
  No, we are not exaggerating. The human eye cannot. No machine can either

- o A happy vision team has (at least) seven players.
  This consists of engineers who specialise in mechanical handling, lighting, optics, video sensor technology, electronic hardware, software, vision system integration.

Alternative Methods of Inspection

- o If a person cannot see the fault, then the machine cannot do so, either.
  The human eye is remarkably adept and versatile. In contrast, a vision system is clumsy and unsophisticated, although it may be faster and more reliable.

- o What a person cannot see, a machine vison system cannot detect.
  It is a good maxim to admit defeat sometimes as this will gain customer confidence, in the long term.

- o It may be cheaper to hire a person to inspect the widgets
  However, a machine may be faster, more consistent and reliable. Be prepared to argue this point with the customer.

Mechanical Handling

- o However deformed the widgets are, they must all pass through the inspection system without jamming.

  If the full range of defective widgets cannot be fed properly through the inspection system, then it is of no use whatsoever. It is an irony that one of the main aims of automated visual inspection is to preventing jamming of a mechanical sub-system, such as an assembly machine.

- o If the parts feed mechanical of the inspection system can go wrong, it most certainly will and the camera will be crushed.

  Be prepared to sacrifice the camera, lighting and/or optical sub-systems, in the event of a failure of the feed mechanism. Design the system accordingly.

Lighting

- o The lighting is not constant.

  Lighting is never constant in either time or in space.

- o Never use software to compensate for a poor lighting system.

  It is not cost effective and will result in a poor system design.

- o It is cheaper to add a light-proof shroud to keep sun-light away from the object as being inspected than modify the software.

Optics

- o Nothing exceeds the speed of light.

  Any processing that can be done optically will save a lot of computer processing later.

- o It is all done by mirrors.

  Wishful thinking, in view of the previous remark.

Image resolution

- o A feature whose diameter is equal to 1% of the width of the camera's field of view, requires a minimum image resolution is 256*256 or better.

  This is a practical application of Nyquist's Sampling Theorem

- o A (100*100) picture is worth 10000 words.

  The ancients were very astute when they realised that a digital image requires the storage and processing of a lot of data.

Related disciplines

- o Machine vision research is not a part-time activity for workers in Image Processing, Pattern Recognition, or Artificial Intelligence.

  Some people think it is, unfortunately. The solutions they offer to industrial inspection problems are, at best, unreliable and over-complicated.

- o Machine vision is not a scientific, discipline.

  Machine vision is not an exercise in philosophy but an engineering project.

Environmental protection

- o Protect the machine from the work place.

  A factory is a hostile place, with lots of dirt, tampering fingers, etc.

- o Protect the work place from the machine.

  Protect eyes from flashing lights, lasers, etc. Make sure that the inspection machine does not shed bits, such as nuts, bolts, etc. and contaminate food products, pharmaceuticals, etc.

- o It is cheaper to pay for a shroud to keep light in than to pay compensation for causing epileptic fits.

- o The lens may not fit the workman's camera at home, but he thinks it will.

  Be aware of light fingered workers causing damage by removeing pieces that will fit their

- o He is a good worker likes to keep things clean - he washes down all of the equipment using a hose-pipe, every afternoon.

  This is quotaion from one factory manager about a dedicated, but uninformed worker who does not realise the potential damage and danger his actions could cause. It is imperative therefore that the vision equipment be made safe and robust.

- o Adjustment of the camera is achieved using a 1kg hammer.

  Vision engineer will be horrified at this prospect but it will happen.

- o Factories are dirty places

  The electrical power supply is noisy. The air supply, for pneumatic equipment, also carries dirt, moisture and oil. Dirt, dust, moisture, fumes, spray, etc. all abound in the local atmosphere.

Working with the system in the factory

Several of these points have been suggested by Hollingum [Hol84]

o Do not assume that the factory workers are computer literate.

Software should be designed in such a way that it can be used with minimal computer skills.

o The people who will make sure that the machine will not work are standing beside it.

So the vision system should try persuade them that it is actually in their interests (as well as his) to work in coooperation with the treasured vision system, not against it.

o A picture is worth ten thousand words.

Give the workers a televison program to watch. A visual display, showing performance statistics opf the vision system and explaining its operation is well worth having, even though it may not seem to be esssential. People "understad" pictures, so a visual display is also useful for fault finding.

o The service schedule of the vision system should be compatible with the production line.

If it is not, the vision system will not fit into the factory environment properly.

o "Will the inclusion of the machine vision system affect the production speed?"

o "Will the manufacturing process have to be modified to accommodate the introduction of the vision system?"

o "Will the production line have to be retrofitted with the automated vision system, or does the vision integrator have total control over the inspection environment?"

o "Will the vision system require custom plant process and/or environment changes?"

o "As the production demands change, can the vision system be easily reconfigured?"

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