ROBOTIC TECHNOLOGY

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Chapter 1

Second generation robotics and robot vision

Professor Alan Pugh

1. Introduction

During the early years of their existence, Industrial Robots represented a solution in search of a problem. At the first International Symposium on Industrial Robots held in Chicago in 1970[1] the delegates were treated to a brief catalogue of robot applications in industries which were invariably hot, smelly and involved jobs requiring a great deal of muscle power. This was the era when the industrial robot was a mere curiosity and its existence was known only to a relatively few informed industrialists. It was the combination of the industrial robot with the problem of spot welding automobile bodies which allowed the versatility of the industrial robot to be properly exploited. This single application transformed the industrial robot scene overnight which resulted in an escalation of the number of robots employed in industry coupled with a liberal coverage in the media which in turn stimulated interest to extend the application of industrial robots to other industrial tasks.

Despite the increasing use of robots in industries having a hostile environment – for example dyecasting and forging – the greater success in application has hitherto been in areas where precise contact with the work place has not been an essential ingredient of the application.[2] In addition to spot welding which falls into this category, paint spraying has been a popular and successful application and considerable success in recent years has been established with seam welding. While the industrial robot was originally conceived with a point-to-point mode of operation, it has been the continuous path mode of operation which has dominated most industrial robot applications. The situation existing now is that robots have become a natural and essential feature for the establishment of a manufacturing process particularly if this is being assembled on a green-field factory site. No longer do potential users need to wait for some adventurous industrialist to experiment with applications for the first time; most of this has been done and applications in the *non-sensory* handling and processing areas are well catalogued. Further, developments in robot structures and mechanisms now give the user a superb range of devices/products from which to choose as any visit to an exhibition of robots will demonstrate.

2. Where is 'generation 2'?

From the very beginning of industrial robot technology, the prospect of intelligent control coupled to environmental sensors has been 'just around the corner'. That 'corner' is now over ten years old and still no really satisfactory realisation of the 'second generation' has been forthcoming. The impressive and promising demonstrations of 'artificial intelligence' at the First International Symposium[1] gave way to more relevant realisations of sensory interaction during the 1970's and a few commercial vision systems are now available.[3,4,5] These however, represent the product of research of about a decade ago and demand a high contrast image for reliable operation.

Cost too plays its part as a deterrent in the sluggish approach of the 'second generation'. We see again the natural reluctance of industrial users not wishing to be first in the field. Acknowledging that substantial developments might exist behind the 'closed doors' of industrial confidentiality, only a few brave experiments towards the 'second generation' have appeared in the technical press. Incentive plays its part in the use of sensory control for certain applications and the microelectronic industry has provided a need for such radical thinking. Examples of this work have been published for some time.[6,7] The need for vision in this industry is associated with the high degree of visual feedback required during the act of device fabrication and assembly and the substantial geometric content of integrated circuit pellets has encouraged the application of machine vision to the problem of automatic alignment and wire bonding. The important aspect of this application which has demonstrated reliable operation must be the relative ease of control of the workplace and the illumination of the assembly area.

Can this success in the use of sensory control be regarded as a realisation of the 'generation 2' robot? Some would argue that it does but most would not accept the specialist mechanised handling as representative of versatile 'programmable automation'. Published attempts of sensory control of robots for shop-floor application are difficult to find. Single experimental applications of both visual and tactile feedback have been implemented although we have an example in the United Kingdom of a company marketing as a standard feature a vision controller for paint spraying[8] which is supported by several years of operating experience.

The application areas for the first generation robots are rarely associated with automated assembly excepting the applications of non-programmable placement devices (or robots). The breakthrough required to extend the application of programmable robots into automated assembly which will open the door to flexible manufacturing systems can only be realised with sensory control to support the assembly process. Despite recent developments in robot architecture,[9] no programmable robot offers the kind of positioning precision to permit reliable assembly to take place without innovations of sensory control of the simplicity of the 'remote centre compliance'.[10] Automated programmable assembly coupled with sensory interactive handling represents the goal which best defines 'generation 2' robotics. The manufacturing areas which involve small to medium sized batches dominate in the industrial scene and those are the areas which are starved of automated solutions. To achieve success in sector, a great deal of work is still required before the flexibility offered by highly expensive 'generation 2' devices can be justified.

3. Vision research

It is perhaps vision more than the senses of touch and hearing which has attracted the greatest research effort. However, robot vision is frequently confused with vision applied to automated inspection and even the artificial intelligence aspects of scene analysis. If an uninformed comparison is made between the technology of picture processing and the requirements of robot vision it is not possible to reconcile the apparent divide which exists between the two.

The essential requirements for success in robot vision might be summarised as follows:

low cost
reliable operation
fundamental simplicity
fast image processing
ease of scene illumination

These requirements are often diametrically opposed to the results of research effort published by research organisations. The processing of grey-scale images at high resolution often provides impressive results but inevitably this is achieved at the expense of processor architecture and processing time. Dedicated image processing systems[11] will attack the problem of processing speed in a most impressive way but there is often a desire on the part of many researchers to identify an area of technological challenge in image processing to satisfy their own research motivation rather than attempt a simplification of the imaging problems.

Probably the single aspect which causes difficulty but often overlooked is the control of illumination of the work area. This problem has been attacked by some researchers using 'planes of light'[12,13] which might be regarded as a primitive application of structured lighting i.e. super-imposing on the work area a geometric pattern of light which is distorted by the work pieces. The success of this approach is manifested in the simplicity of binary image processing and a reduction in the magnitude of visual data to be analysed.[14] Developments of early demonstrations of robot vision using back lighting of the work area have reached a stage of restricted industrial application.[15] However, a feature of sensory techniques which have industrial potential, is that they are often application specific and cannot be applied generally.

The experiments linking image processing of televised images with robot applications[16] (for example) are in their infancy at present; the cost is high and the reliability of image processing is unlikely to be satisfactory for some time to come.

4. Image resolution

Sensing for robot applications is not dependent on a relentless pursuit for devices with higher and higher resolution. The fundamental consideration must be in the selection of *optimum* resolution for the task to be executed. There is a tendency to assume that the higher the resolution then the greater is the application range for the system. At this point in our evolution, we are not exploiting the 'state of the art' as much as we should. Considerable success has been achieved using a resolution as low as 50 x 50.[6] With serial processing architectures, this resolution will generate quite sufficient grey-scale data to test the ingenuity of image processing algorithms! Should processing time approach about 0.5 seconds, this will be noticeable in a robot associated with handling. However, for welding applications, the image processing time must be even faster.

High resolution systems are required in applications involving automated inspection and picture data retrieval where speed is sometimes not such an important criterion. This must not be confused with the needs of sensory robot systems.

5. The sensor crisis

Perhaps the key issue in the production of the sensory robot is the availability of suitable sensors. The following represents a summary of sensing requirements for robot applications:

presence
range
single axis measurement (or displacement)
2-dimensional location/position
3-dimensional location/position
thermal
force

for which the following sensing devices or methods are available.

Vision
Photo-detector
Linear array
Area array
T.V. camera
Laser (triangulation)
Laser (time of flight)
Optical fibre

Other
Infra red
Radar
Magnetic proximity
Ionising radiation

Acoustic
Ultrasonic detectors/emitters
Ultrasonic arrays
Microphones (voice control)

Tactile
Probe
Strain gauge
Piezoelectric
Carbon materials
Discrete arrays
Integrated arrays

The only satisfactory location for sensors is on the robot manipulator itself at or near the end effector.[14,17] Locating an image sensor above the work area of a robot suffers from the disadvantage that the robot manipulator will obscure its own work area and the metric displacement of the end effector from its destination must be measured in an absolute rather than a relative way. Siting the sensor on the end effector allows relative measurements to be taken reducing considerably the need for calibration of mechanical position and the need for imaging linearity. Sensory feedback in this situation can be reduced to the simplicity of range finding in some applications.

What is missing from the sensor market are devices specifically tailored to be integrated close to the gripper jaws. The promise of solid-state arrays for this particular application has not materialised which is primarily due to the commercial incentives associated with the television industry. It might be accurate to predict that over the next decade imaging devices manufactured primarily for the television market will be both small and cheap enough to be useful in robot applications. However, at present, area array cameras are extremely expensive and, while smaller than most thermionic tube cameras, are far too large to be installed in the region of a gripper. Most of the early prototype arrays of modest resolution have been abandoned.

It is not an exaggeration to suggest that no imaging sensors exist which are ideally suited for robot applications. The use of dynamic RAM devices for image purposes[17] has proved to be a minor breakthrough and gives an indication of the rugged approach which is needed to achieve success. Some researchers have attacked the problem of size reduction by using coherent fibre optic to retrieve an image from the gripper area[16] which imposes a cost penalty on the total system. This approach can, however, exploit a fundamental property of optical fibre in that a bundle of coherent fibres can be subdivided to allow a single high-resolution imaging device to be used to retrieve and combine a number of lower resolution images from various parts of the work area including the gripper – with each subdivided bundle associated with its own optical arrangements.[18,19]

Linear arrays have been used in situations involving parts moving on a conveyor in such a way that mechanical motion is used to generate one axis of a 2-dimensional image.[12,18] There is no reason why the same technique should not be associated with a robot manipulated by using the motion of the end effector to generate a 2-dimensional image. Also implied here is the possibility of using circular scanning of the work area or even taking a stationary image from a linear array.

Tactile sensing is required in situations involving placement. Both active and passive compliant sensors[20,10] have not only been successfully demonstrated but have experienced a period of development and application in the field. The situation surrounding tactile array sensors is quite different. Because the tactile arrays are essentially discrete in design, they are inevitably clumsy and are associated with very low resolution. Interesting experiments have been reported[21,22,23,24] and an exciting development for a VLSI tactile sensors is to be published.[25]

Experiments with range sensing have been liberally researched and some success has been achieved with acoustic sensors and optical sensors (including lasers). The whisker probe[24] can now be replaced by a laser alternative with obvious advantages. Laser range finding is well developed but under-used in robot applications although the use of laser probes sited on the end effector of an industrial robot makes a natural automated dimensional inspection system.

It is clear from this brief catalogue of sensing methods that a great deal of chaos surrounds the sensor world. What we must work towards is some element of modularity in sensor design to allow for the optimum sensing method to be incorporated into a given application. No single sensor can provide the solution to all problems and bigger does not always mean better. However, the recent exciting developments in 'smart sensors' which incorporate primitive image processing (front-end processing) will be most welcome. A comprehensive survey and assessment of robotic sensors has been published by Nitzan.[26]

6. Languages and software

The involvement of the stored-program computer in the present generation of robots does no more than to provide an alternative to a hard-wired controller excepting that the computer provides an integrated memory facility to retain individual 'programs'.

Software and languages became a reality for most users with the introduction of VAL[27] which incorporates the capability to interpolate linear motion between two points and provides for co-ordinate transformation of axes. Further, VAL allows for transformation between vision and machine co-ordinates.[28] Machine training or learning using VAL can be achieved 'off-line' rather than the 'teach by showing' which is the method used by the majority of present generation robots.

Work is now under way on languages for assembly[29,30] which will give to the sensory robot system autonomy of action within the requirements of the assembly task. Further, a common assembly language will permit the same instructions to be repeated on different robot hardware in the same way that computer programs written in a common language can be executed on different machines. The lesson to be learned here is that we must discipline ourselves to a common assembly language before a proliferation of languages creates a situation disorder. It is still early days to consider an assembly task being executed by an 'off line' assembly language as part of a CAD/CAM operation. One of the stepping stones required in this revolutionary process is the establishment of some 'bench marks' to compare and test the relative merits of assembly languages.

7. Concluding remarks

The ingredients which comprise the second generation robot are:

mechanisms with speed and precision
cheap and reliable sensors
elegant and rugged software

In all of these areas there exists a significant deficiency of development and perhaps a need for an innovative breakthrough. We have seen previously the shortfall in sensor requirements and the need for good supporting software has only been admitted in recent times. With the exception of mechanisms specifically designed for dedicated tasks, no existing robot device alone can really provide the precision necessary for assembly operations. A promising way to proceed is to use a programmable high speed manipulator for coarse positioning, coupled with a 'floating' table which incorporates features for fine positioning.[31]

When it is remembered that *research* demonstrations of 'generation 2' robots have been available over the past decade[32,33,34,35,36,37] it is salutory to recognise that predictions for the future made over this period have not been realised. A survey of the current situation in robot vision has been published recently.[38] It would be a brave person who now predicted where and when the 'generation 2' robot would take its place in industry. With the wisdom of hindsight we know that there is still a vast amount of research and development required coupled with an industrial need for a 'generation 2' robot. Perhaps this need will first appear in the textile, pottery or confectionery industries[39] to provide the 'shot in the arm' for 'generation 2' just as spot welding did for 'generation 1' a decade ago.

Over the past two years, the United Kingdom has introduced government funding to aid and support industrial applications as well as providing a co-ordination programme of research and development in the universities. Surveys of industrial requirements and research partnerships in the U.K. have recently been published.[40,41]

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