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Flexible part-feeding system for machine loading and assembly.
Part I. A state-of-the-art survey

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Abstract

The cost to feed parts to a robot for either machine loading or assembly in a flexible manufacturing system (FMS) has often been underestimated. A recent survey on part-feeding methods applicable to a board class of flexible manufacturing systems has indicated that part-feeding may comprise two-thirds of the overall investment and are usually the source of a large percentage of work stoppage and defects. The lack of an off-the-shelf data-driven software-control generic part-presenter satisfying both cost and functional requirements is a major source of problems which prevent the flexibility of the overall flexible manufacturing automation to be fully exploited.

In this article, the state-of-the-art of part-presentation techniques for flexible part-feeding is reviewed. Special attention has been placed on the use of computer vision techniques which has potentials in adding considerably to flexibility by simplifying grippers, component feeders, and location tooling, and by reducing engineering time required to implement it. The use of computer vision in real-time part-presentation is evaluated in terms of its on-line computational requirements. The evaluation was performed on an experimental prototype based on a breadboard configuration using off-the-shelf hardware. Factors that limit standard machine vision techniques for part feeding are addressed in terms of their reliability and cost.

1. Introduction

The competition for consumer market has motivated manufacturers to direct their production efforts towards low-volume (batch) manufacturing of many varieties of similar products. This trend has been further accelerated by the rapid advancement of robotic technologies which offer relatively high performance at reasonable cost, consistency in product quality and avoid direct labor in a flexible automated factory or a modular manufacturing workstation.

During the past two decades, considerably progress has been made in the development of flexible sub-systems, such as computer-numerical-controlled (CNC) machine tools, automated conveyance networks, and automated-guided-vehicle (AGV) to transfer parts and tools between stations, coordinating measuring measuring machines (CMM), and in the computer network communication and control systems for undertaking the overall coordination of the various sub-systems. Significant advancements have also been achieved in system scheduling, material flow strategies, assembly cell layout, and production planning. However, the cost and complexity of the equipment between the sub-systems and the manufacturing system has often been underestimated. The term "part-feeding" refers here as feeding workpiece from pallets using a pre-programmed robot for subsequent processes such as machining or assembly. A recent survey on part-feeding methods applicable to a broad class of flexible manufacturing systems (FMS) has indicated that the flexibility of the overall flexible automated factory cannot be fully exploited due to a lack of flexible part-feeding sub-systems, which may comprise two-thirds of the overall investment and are usually the source of a large percentage of work stoppages and defects. The problems encountered worldwide [1–7] in FMS provides evidence of this concern and research need.

The aim of the work presented here and in Part II of this article is to establish the engineering science needed for generic part-presentation, which ultimately leads to the creation of a flexible computer-controlled system for feeding parts into machine tools or assembly processes that combined maximum flexibility and reliability with minimum cost and cycle-time. The state-of-the-art of part-presentation techniques for flexible part-feeding is reviewed in Part I of this article, with special attention has been placed on the use of computer vision techniques. The use of computer vision in real-time part-presentation is evaluated in terms of its on-line computational requirements, reliability, and cost. The evaluated was performed on an experimental prototype based on a breadboard configuration using off-the-shelf hardware. A cost-effective solution to overcome factors that limit standard machine vision techniques for practical part feeding is described in Part II of this article.

The remaining report is organized as follows: Section 2 provides an overview of current part-feeding approaches and part-presentation techniques. Factors which limits the current computer vision technique for part presentation is reviewed Section 3. The concept of retroreflective vision sensing is presented in Section 4, and the experimental evaluation results are given in Section 5. The conclusions and future challenges of vision-guided part-feeding are summarized in Section 6.

2. Part-feeding approaches

Significant efforts have been directed worldwide to achieve a high degree of flexibility in part-feeding. These efforts involves both product design and layout considerations in order that industrial robots are capable of feeding parts to manufacturing processes from some forms of pallets which may be packaged by manufacturers or specifically designed in-house for custom factory layout. The following sub-sections present an overview of currently available part-feeding configurations and part-presentation techniques applicable to a broad class of manufacturing systems.

2.1. An overview of part-feeding approaches

The manner in which parts are fed to robots in a flexible automation system depends on the nature of the manufacturing processes, the product design, and the material handling system as a whole. The manufacturing systems are broadly classified as electronic product assembly, subassembly of electrical and mechanical components, and large-scale manufacturing.

2.1.1. Electronic product assembly

Flexible workcells are commonly used [7–9] for the assembly of printed-circuit-boards (PCB), where a combination of interchangeable part-feeding mechanisms are used to present parts to robots. The primary drawback of this feeding method is the limited accessibility of part styles, particularly when only a few of each kind from thousands of styles may be used. Several alternatives were suggested to extend the robot accessibility to large number of parts were reported. An ingenuous data-driven system was proposed by Cowan and Davies [10] to allow the robot to access to 2000 different parts delivered in magazines, tapes, or other modular dispensing systems, which are mounted on up to seven carousels arranged at 30° intervals around the robot.

Other alternatives are (1) the use of kitting cells, in which all components to be assembled are kitted in a loosely palletized waffle packs and followed by more accurately located using standard machine vision, and (2) the use of accurate totes for robot handling suggested in a study by Conradson et al. [11].

2.1.2. Sub-assembly of electrical and mechanical components

The degree of flexibility of assembly small components involves both product design and layout considerations extensively. The planning, layout and implementation of flexible cell for assembly electrical components consisted of 15–70 parts were discussed by Lotter [3]. Vibratory feeders are most commonly used to feed and to orient small components. Lotter found that the total availability of a flexible assembly cell falls due to the lack of programmable part-presentation.

Perhaps, flexible assembly line [12] such as one reported for Hitachi's video machine assembly in Japan often used for subassembly of electrical and/or mechanical components. The line typically composes of self-contained independent stations which can be engaged or disengaged as required to allow adaptability in connection with model change. Modular part-feeding equipment such as vibratory feeder bowls and special-purpose trays are commonly used to feed parts. Recently, an alternative flexible feeding setup known as "Mark II" has been presented by Arnstrom and Grondahl [13]. The principle of "Mark II" system is to allow standard carriers or pallets to present a large number of different part-types to a robot. Each pallet carries a large number of identical parts (size: 10–150 mm), unoriented but with the right-side-up, and placed on a flat board (typical size: 400 mm×600 mm). Standard machine vision was used to detect the orientation of the parts.

2.1.3. Large-scale manufacturing

In the field of large-scale manufacturing such as automobile manufacturing, engine assembly, and machining processes, where the setup time of specialized tools for each task in excessive, the work is generally distributed into several cycle zones. As an example, actual cutting time (production time) represents a value between 5% and 20% of average machine utilization time which includes non-productive time accountable by workpiece load/unload, tool change/setting, and workpiece inspection/correction [14, 15].

To avoid high level of wear and tear on tools due to constant conversion, the cycle zone is commonly divided into individual operating cells which may be inter-connected in series, parallel, or a combination of series and parallel. A typical workcell consists of a robot, a part-feeder, an end-of-arm tooling section, and the manufacturing process. The parts are contained in a regularly spaced pallet, which are transported by means of an AGV or a conveyor to the loading table and are fed to process by the robot. The most common approach in automated part-presentation for machine loading is the use of specially designed pallets for each part family to maintain sufficient position accuracy for a completely pre-programmed robot picking.

Schmidt [16] presented an alternative system arrangement for engine assembly. The base unit of an engine is loaded at the system entry on an AGV and remains on the AGV throughout the entire course of the continuous assembly flow. The AGV serves at the same time both as a workstation for manual assembly as well as a conveyor unit between work islands which are equivalent in function and are fully equipped with the same tools.

2.2. Part-presentation techniques

The basic kinds of part-feeding may be classified as follows: (1) mechanical feeders which is designed to feed and to orient the parts dedicated part-feeding apparatus, (2) dimensionally dedicated pallets which are specially designed for each part family to maintain the position/orientation, and (3) machine vision.

2.2.1. Mechanical feeders

The commonly used mechanical feeders for robotic assembly are specially-tooled vibratory bowl feeders, multi-part vibratory feeders, and programmable belt feeders [17].

Vibratory bowl feeders. Vibratory bowl feeders [17] are most commonly used mechanical feeders for robotic assembly. These feeders, in general, are not designed to be easily converted to feed new part types. Typically change-over would involve replacing the bowl, orientation track, feed track, and escapement. Only the vibratory drive unit coule be re-used, which is approximately 30% of the feeder cost.

Multi-part vibratory feeders. Several design concepts of multi-part vibratory feeders have been investigated as reported by Boothroyd and Dewhurst [17]. These design concepts aim at reducing the cost of the vibratory feeders by sharing the general-purpose hardware cost over several parts and by reducing the special-purpose tooling cost. Multi-part vibratory feeders are available in two forms: bowl type and in-line type.

In general, to changeover this multi-part vibratory feeder to other part types, the orienting tracks must be replaced.

Belt feeders. In programmable belt feeders [17,20], parts are fed by a conveyer belt or a revolving disk. The orienting systems used on these belt feeders may be an optical sensor or a mechanical device. Since a robot gripper can grasp parts from a queue on the feeder itself, belt feeders do not require an special-purpose tooling for feed track or escapement and thus offer several advantages over the vibratory feeder for robotic assembly.

In general, the cost of part-feeding consists of (1) the general-purpose equipment cost of the feeder, the cost of the special-purpose tooling which cannot be re-used for subsequent batches, and (3) the labour cost involved in each changeover to different part types. The relative cost of using different part-presentation methods in robotic assembly was discussed in [17]. For large volume manufacturing the employment of the dedicated mechanical part-feeding apparatus may be justified. However, mechanical feeders consume a lot of room around the workcell, often fail due to jamming, and most significantly, generally require re-tooled when a component is changed or tool wear caused by jamming.

2.2.2. Dimensionally delicated pallets

Perhaps, one of the most common approaches is the use of specially designed trays or totes for each part family to maintain sufficient position accuracy for a completely pre-programmed robot picking. A particular form of these dimensionally precise feeders is known as tape-and-reel for feeding parts of relatively small sizes, which can be placed on tapes of standard width. For some devices that are large, heavy, or of ceramic, or having fragile leads, tapes are very expensive and impractical.

In general, the success of dimensionally delicated pallets for small volume production is achieved at the expense of operational cost, implementation time, and flexibility. The high operational cost is accountable for excessive packaging costs for transport, precise alignment of the pallet, and re-engineering for new pallet designs.

2.2.3. Vision-aided mechanical feeders

Several researchers attempted to separate the function of orienting from feeding [1,21–24], where vibratory feeders are most commonly used apparatus to feed workpieces into a single track without orienting in order to reduce jamming. Parts of several different types are fed but not oriented from a vibratory feeder. In most cases, the workpieces must be held by a mechanical pusher against a pair of orthogonal datum planes on a relatively flat surface with the "right-side-up". A machine vision system is then used to locate and/or to sort the orientation of the parts using two-dimensional binary images which is a great deal easier to store and to process. A line-scan camera with back lighting is commonly used to create the silhouettes of the workpieces, and in some cases, the product designs were reviewed to simplify the vision algorithm and to reduce the system cost. Back lighting, however, has a severe drawback since it must be accompanied with some form of mechanical feeders and generic trays can not be used.

2.2.4. General machine vision

For flexible manufacturing, where a large variety of product sizes and component types are encountered, the part-feeding system must have the ability to adapt to a changing product design without costly hardware re-design or time-consuming software re-engineering. This need has been addressed as a general industrial vision based bin-picking problem by several authors. Binary images which are a great deal easier to store and to process are commonly used. They are generated by enhancing a gray level image using a threshold value which separates the two groups of grey-levels from a histogram. Ideally, the histogram is characterized by two peaks corresponding roughly to the object and the background with a valley in between.

The generation of binary image, however, requires an essentially two-dimensional pattern of high object-to-background contrast. In practice, the picture cells corresponding to the object will not all have exactly the same gray-level. The gray levels of an image depends on the object's geometry and surface reflectance. In addition, a number of non-predicable factors such as measurement noise, the uniformity of the surface reflectivity, or the uniformity of illumination, a spread in grey-level may occur on both the object and the background. These non-predictable factors often contaminate the binary image and must be "filtered" prior to the computation of the object location and orientation. The "filtering" may be achieved, in general, at the expense of computation time by image segmentation [13], pattern matching [24], or ternery image reduction [25].

Alternatively, machine visions which rely on specialized lighting system design for each part family to generate silhouettes require a prior knowledge on the object geometry and reflectance to enhance the image quality. However, variations in surface reflectance coupled with algorithm computational demands often make this approach too expensive, unreliable, and slow for practical on-line part presentation. Furthermore, the parts are often in separate, regularly-spaced locations in totes, pallets, or kits. In these cases the part location is approximately known, and the problem is to precisely locate known objects within a allowable production cycle-time.

3. Problems associated with computer vision for part presentation

In the last three decades, computer vision has been extensively studied in many application areas which includes character recognition, medical diagnosis, target detection, and remote sensing. Although it has been well recognized in the past decade that vision can add considerably to flexibility by simplifying grippers, component feeders, and location tooling, and can reduce the engineering time required to implement it, the capabilities of commercial vision systems for part-presentation tasks are still very primitive. One reason for this slow progress is that part-presentation tasks require sophisticated vision interpretation, yet demand low-cost and high-speed, accuracy, reliability, and flexibility. Several factors limit the commercially available computer vision techniques for practical part-feeding as follows:

3.1. Machine vision emulating human perception

Since the entertainment industry is still a far more lucrative market for camera manufacturers than machine vision, few image sensors and cameras deviate from television standard. Many vision system of todays are integrated using off-the-shelf cameras such as entertainment and surveillance type cameras, which are created for human eyes and brains rather than for machine perception. Biological vision tends to be insensitive to absolute light intensity and spatial accuracy. Video camera tends to suffer the same biases as humans do. To compensate for the biases, conventional machine vision techniques rely on the design of lighting systems to enhance the image for processing [26–31].

In manufacturing automation applications, the processing speed of acquiring and analyzing an image must be comparable to the speed of execution of the specific task. The attempt to duplicate human perception by obtaining a three-dimensional detailed image of the part often calls for time-consuming computation and does not necessarily determine the location and orientation of a given part with the accuracy required for successful part-acquisition by the robot. Moderate location inaccuracies pose no difficulty for human operators since they use vision, hand-eye coordination, and sense of touch to locate and correctly load the part. A comprehensive review of the available image processing techniques is given by Chin and Dyer [32].

3.2. Lack of appropriate hardware

The components required for building a conventional vision system generally include a video camera which outputs standard RS170 video signal, a frame grabber board which uses a flash analog-to-digital (A/D) converter to change the RS170 video signal into a series of *n* bit brightness values (grey levels) and fast memory components to store them, and a micro-computer which computes the location and orientation of the part. In addition to the error resulting from the time mis-matching between image acquisition hardware and the computer hardware, the

RS170 video signal limits the read out of a complete frame at a rate of 30 fps (frame per second). An image of m rows by n columns has $m \times n$ pixels and so requires a substantial amount of memory and loading time. Among these $m \times n$ pixels, only a few carry the information on which a vision system will base a decision. As noted in several references [33–35], this generally makes "frame grabbing" inherently wasteful.

Apart from the lack of appropriate hardware and the high equipment cost, two other major problems often associated with the use of RS170 video vision system are poor reliability and excessive image processing time, both of which depend on the illumination technique, the complexity of the geometry, and the surface reflectance of both the background and the objects to be handled.

3.3. Lack of application specifications

Light and its measurements are among the least understood technologies. Discussion and communication of desired operating parameters are complicated by a plethora of nomenclatures for seemingly similar units of measurements. Furthermore, system specifications for illumination are often vague or may be left to the final user. Expensive digital devices have long been paid for the illumination deficiencies. When illumination deficiencies become apparent, it is then the critical light parameters such as luminous intensity, illumination uniformity, spectral output, and image spectral irradiance become an unwelcome part of our vocabulary.

Most of the literature on structured illumination systems for flexible manufacturing, whether they use dark-field or bright-field illumination, are based on techniques which require á prior knowledge of the object geometry and surface reflectance. Although the use of dedicated illumination techniques for each part family has proven useful for automating product inspection, they have been found in practice to be too expensive, less flexible, and less reliable than required for on-line real-time part-presentation.

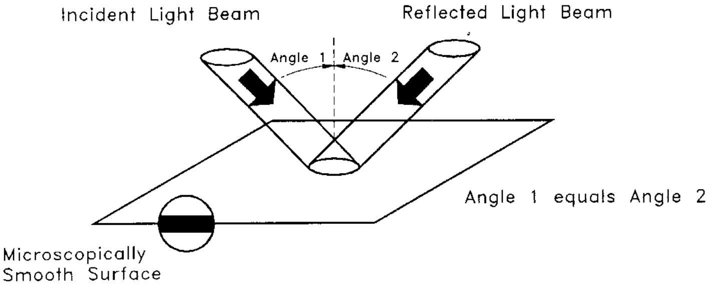
4. Retroreflective vision sensing

Most surfaces on objects exhibit a combination of diffuse and specular reflection as illustrated in Figs. 1a and 1b respectively. A point on an ideal diffuse reflecting surface appears equally bright from all viewing directions. Surfaces covered with papers and matte paints may be considered as reasonable approximations. An ideal specular reflector is one which reflects any incident light ray as a single ray in the same plane as the incident ray and the surface normal. The angle between the reflected ray and the incident ray is twice the angle between the normal and the incident ray. A mirror has specular reflection.

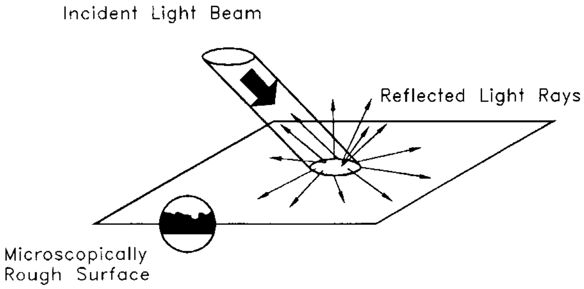
The third reflectance known as retroreflection is not commonly found on the surfaces of objects. The ideal retroreflector returns the incident radiation in the direction from which it came as illustrated in Fig. 1c. Two principles followed to achieve retroreflectivity are prismatic, also known as cube-corner, and spherical lens retroreflection. The principle of prismatic retroreflection is illustrated in Fig. 2a. Incoming lights hit the first surface of the cube-corner and reflect to the real surface which reflects it to the last surface which reflects the light rays back to the source. In the second type, spherical lens, retroreflection is achieved through a combination of a glass sphere (bead) and a reflecting (mirror type) surface placed at the focal point. As illustrated in Fig. 2b, an incoming ray is bent and directed inside and toward the back of the sphere, reflecting off the reflective surface, and after being bent at the exterior of the sphere redirected toward the light source. In practical retroreflectors this characteristic is maintained over a wide variation of the angle made by incident light rays and the normal to the retroreflective surface.

The coefficient of retroreflection of a typical retroreflective sheeting is displayed in Figs. 3b and 3c as a function of observation and entrance angles, where the nomenclature used in standard measurement of retroreflective materials [36,37] is defined, Fig. 3a. Within an angle of 0.2° from the principle axis of incident light, typical retroreflective sheetings reflect with over 250 times the intensity of an ideal diffuse white surface.

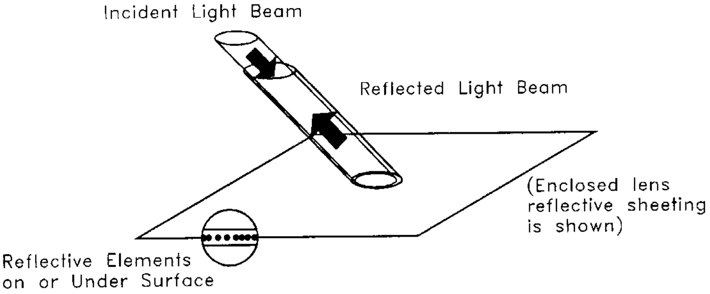
Retroreflective materials have been widely used in traffic control and safety sign on highways and airports [36–38]. Incidentally, the retroreflector has also been used as a non-contact



(a) Specular reflection

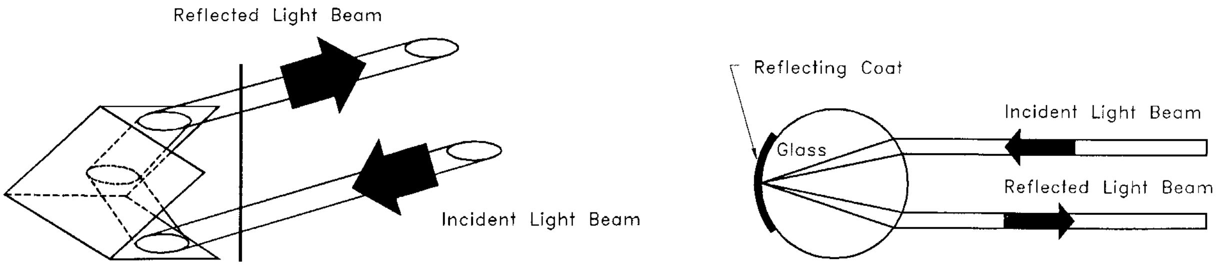


(b) Diffuse reflection



(c) Retroreflection

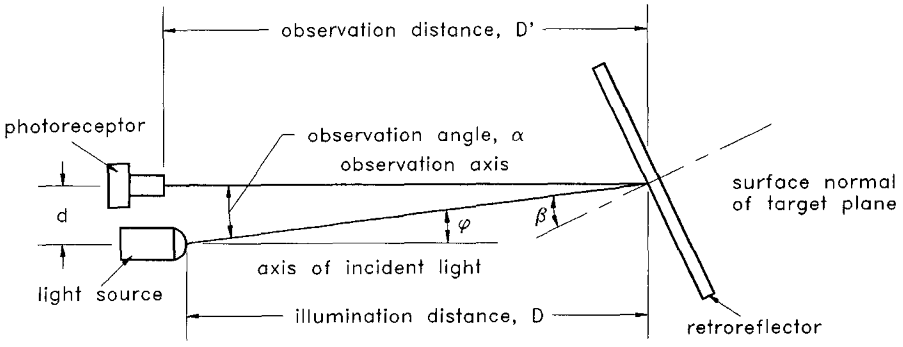
Fig. 1. Typical surface reflection. (a) Specular reflection; (b) diffuse reflection; (c) retroreflection.



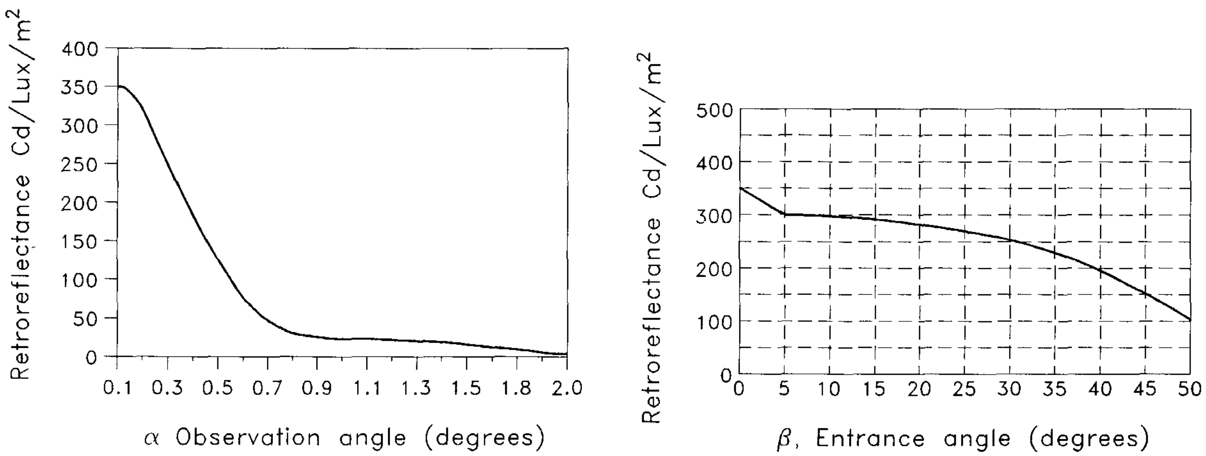
(a) Prismatic or cube–corner

(b) Spherical lens retroreflection

Fig. 2. Principle of retroreflectivity. (a) Prismatic or cube-corner; (b) spherical lens retroreflection.



(a) Nomenclature of retroreflection measurement



(b) Coefficient of retroreflection as function of observation angles

(c) Coefficient of retroreflection as function of entrance angles

Fig. 3. Typical characteristic of retroreflection. (a) Nomenclature of retroreflection measurement; (b) coefficient of retroreflection as function of observation angles; (c) coefficient of retroreflection as function of entrance angles.

position sensor of large space structure [39] and more recently, in field tracking of automated guided vehicles (AGV) [40]. The unique feature of the retroreflective materials as an effective means for generic part-presentation was conceptualized by Lee et al. [41]. The basic principle of retroreflective vision sensing for part-presentation is to use retroreflective surfaces to maximize the ability of a vision system to reliably and quickly locate parts. One way is to make the surface of a pallet retroreflective so that it can be made to appear much brighter than objects on it.

Alternatively, retroreflective landmarks can be intentionally created on objects for location tracking. Since the retroreflective material has a distinctive surface reflectance that is not commonly found in natural or man-made objects, it enables reliable digital images of high object-to-background contrast to be obtained without a prior knowledge of object geometry and surface reflectance. The location and orientation of the part can then be determined with relatively simple, high-speed computation without the need for a detailed reflectance map of the part to be handled.

5. Experimental evaluation

A breadboard configuration using off-the-shelf hardware was investigated. A General Electric TN2700 CID camera [42] (currently manufactured by CID Technologies) was used in this investigation. The CID camera has 484V×377H active pixels of area equal to 13.6 μm×23.4 μm. The camera is mounted on a robot arm which allows the camera to be positioned at any desired location. The silhouette of each part is obtained with the observation axis perpendicular to an plane in which the object is to be characterized. The ability to position the camera relative to the part helps eliminate or reduce any possible shadow.

Twelve HP4101 AlGaAs LED lamps [43] (100 mW each) are evenly spaced at a 25.4 mm (1 inch) diameter from the center of the 16 mm C-mount lens. The LED lamps are chosen not only to match the spectral characteristics of the CID camera, but also because of the low cost, low power consumption, and long life span. The pulse-generating electronic circuit is to obtain high intensity light and to synchronize with the camera at a pulse width of 5 ms and a period of 16.6 ms. A spectral filter of 650 nm was placed in the light path between the LEDs and the lens. The vision camera and its collocated illumination is shown in Fig. 4.

All computations are performed using a standard IBM PC/AT with an Intel-80287 MATH coprocessor with code written in Microsoft C language. The Data Translation frame grabber board DT-2803 was used to acquire the RS-170 image and to display the digitized image (8-bit grey levels, 256×256 elements) on a SONY KV-1311CR color TV monitor.

The time required for real-time part-presentation is accountable to three processing stages: (1) image generation and digitization, (2) image segmentation, and (3) computation of the center and the orientation of the image. In the breadboard configuration, the video camera outputs a RS 170 video signal continuously at a rate of 30 frames/second. The "frame grab" (DT-2803) uses a flash analog-to-digital (A/D) converter to convert the RS 170 video signal from the camera into a series of 8 bit brightness values (grey levels) and fast memory components to store them. The image segmentation and the computation of the location and orientation are performed using the IBM PC/AT.

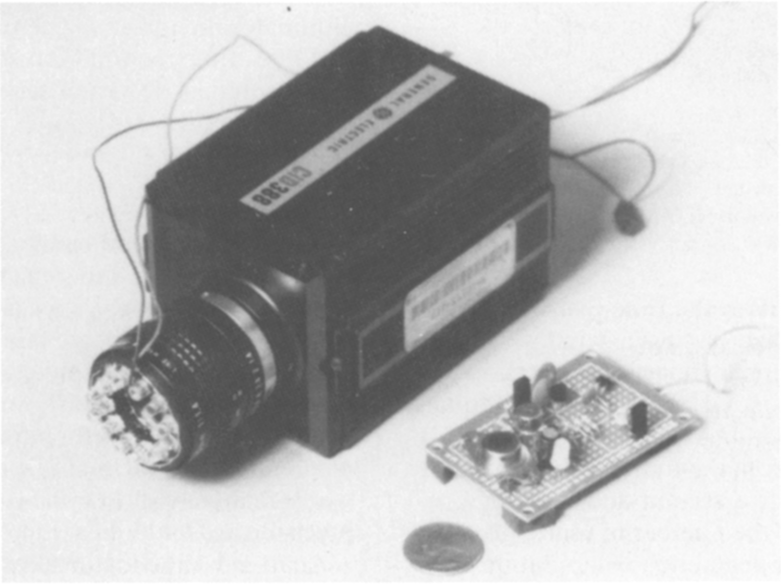


Fig. 4. CID Camera and collocated illumination.

TABLE 1

Estimation of computational time (without image segmentation)

Process	Time (second)
Cature a 256×256 digitized image	0.55
Storing a 50×60 digitized image into computer RAM	≈0[a]
Generation of a 2-D array	0.05
Conversion from gray-levels to binary	0.06
Computation of centroid	0.02
Computation of orientation least-inertia method)	0.3
Total time taken (seconds)	0.98

[a] Time is less than 0.01 second.

TABLE 2

Estimation of computation time (with image segmentation)

Process	Time (second)	
	58×35	128×128
Capture a 256×256 digitized image	0.55	0.55
Storing an $m \times m$ digitized image into computer RAM	~0[b]	0.10
Conversion of grey-scale to binary	0.06	0.38
Image Segmentation	0.43	7.03
Number of separate objects	5	12
Largest object (area in number of pixels)	950	2558
Computation of centroid	~0[b]	0.22
Computation of orientation	0.55[c]	0.54[d]
Data conversion from image-to-object space	~0[b]	~0[b]
Total time taken (second)	1.59	8.82

[b] time is less than 0.01 second.
[c] Least-inertia method was used.
[d] Circular scan was used.

Table 1 summarizes the time distribution for processing an image having a window size of 50×60 pixels, where the image segmentation was not required. The total processing time is approximately 1 second. As illustrated in Table 1 the loading time from the frame grabber into the RAM is about half a second and remains constant regardless of the number of useful pixels to be computed. The remaining computation time is approximately 0.141 ms/pixel. An image of 256 rows by 256 columns has 65536 pixels and so requires a substantial amount of memory and loading time. Among these 65536 pixels, only a few carry the information on which a vision system will base a decision. This generally makes "frame grabbing" inherently wasteful. In addition, significant overhead cost is associated with conventional machine vision system in order to support the redundant system hardwares such as memory, clock synchronization system bus, data communication, and power supply.

The time required for the image segmentation computation depends significantly on the number of unrelated objects in the field of view, noises, and undesired specular reflection. Two experiments were conducted on the breadboard configuration system to investigate the incremental time required for image segmentation. The first involved computation of a small window size of 58×35 elements with five unrelated objects. The second performed computation of a relatively large window size of 128×128 elements with twelve unrelated objects. Since parts located individually in regularly spaced low-cost tray allow a viewing window to be reasonably well defined off-line, the image segmentation is the most time-consuming computation routine as shown in Table 2.

As illustrated in Fig. 5, retroreflective vision sensing which generates reliable high contrast silhouettes with relatively low power illumination eliminates the image segmentation computation and thus, time required for image processing using retroreflective vision sensing would be relatively constant.

6. Conclusions

The survey has indicated that the cost to feed parts to a robot for either machine loading or assembly is excessively expensive. Computer vision systems of today are largely based on video TV standards. These systems, though well developed and available widely in commercial markets, are more suitable for human perception than machine vision for manufacturing applications where relatively short cycle-time, reliability, and precision are required at low cost.

Apart from the high equipment cost, two major problems often associated with the use of standard video camera are poor reliability and

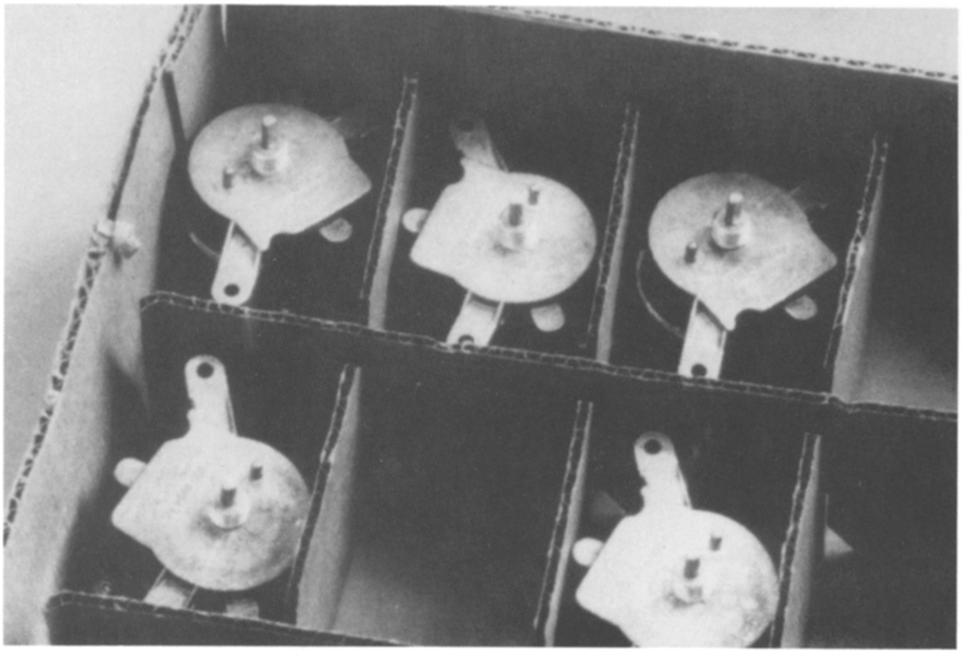


Fig. 5. Digital binary image of machine vision. (a) Typical components in low-cost tray; (b) without retroreflective background; (c) with retroreflective background.

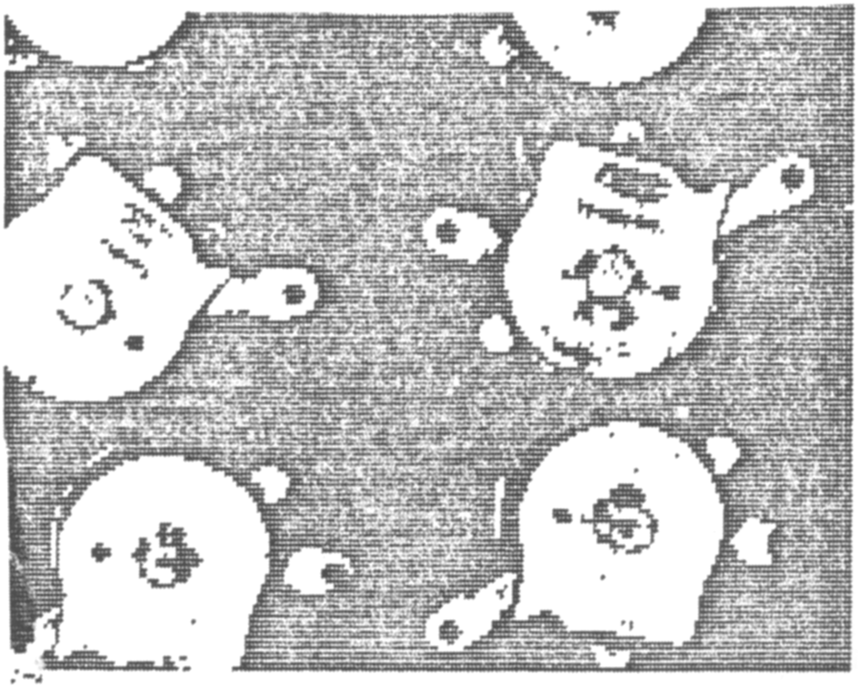


Fig. 5. (b).

excessive image processing time, both of which depend on the illumination technique, the complexity of the geometry, and the surface reflectance of both the background and the objects to be handled.

The concept of giving retroreflective materials

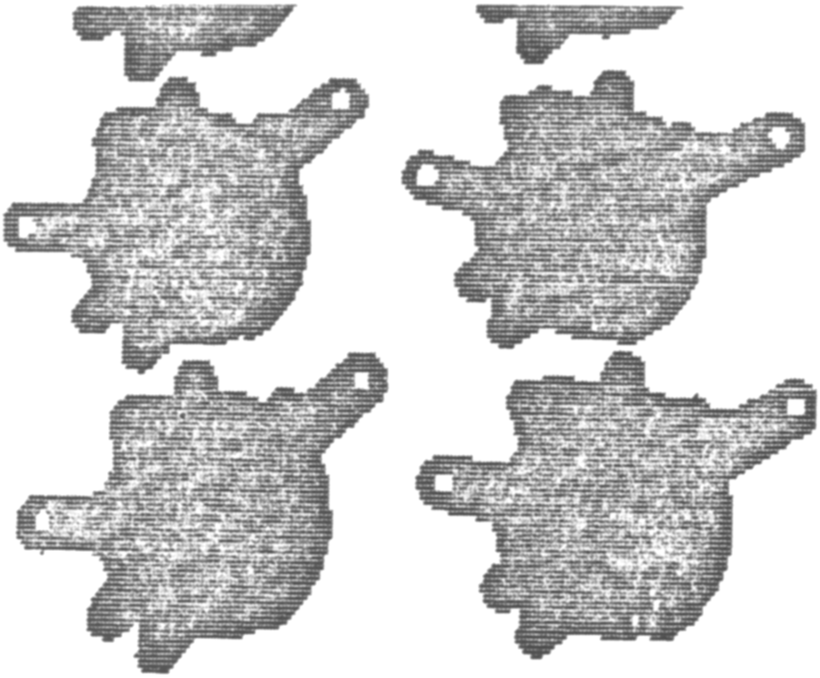


Fig. 5. (c).

an integral role in vision sensing for generic part-presentation has been proven to have significant potentials in improving the vision reliability, reducing the computational load/time, and lowering the cost in implementation for part-feeding.

Clearly, the lack of an off-the-shelf data-driven software control generic part-presenter satisfying both cost and functional requirements is a major source of problems which prevent the flexibility of the overall automation of FMS to be fully exploited.

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