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INDUSTRIAL ROBOTS AND COMPUTER VISION

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Abstract: Computer vision with appropriate simplifying constraints, is providing a powerful sensory tool for robot control and for another important applications. Computer vision supplemented as required by force and torque sensing, can greatly enhance the performance of first generation robots presently limited to operations based on fixed, predetermined actions. The new capabilities include the identification of workpieces, the determination of their position and orientation, and the provision of real-time visual feedback for effecting adaptive corrections of the robot's trajectories. Typical applications selected from real problems in industry are described, and analyzed. Further, there are indicated some approaches to possible solutions.

Key words: Computer vision, industrial applications, artificial intelligence.

1 Introduction

The use of external sensing mechanisms allows a robot to interact with its environment in a flexible manner. This is in contrast to preprogrammed operations in which a robot is "taught" to perform repetitive tasks via a set of programmed functions. Although the latter is by far the most predominant form of operation of present industrial robots, the use of sensing technology to endow machines with a greater degree of intelligence in dealing with their environment. Although proximity, touch, and force sensing play a significant role in the improvement of robot performance, vision is recognized as the most powerful of robot sensory capabilities.

Robot vision may be defined as the process of extracting, characterizing, and interpreting information from images of a three-dimensional world. This process, also commonly referred to as machine or computer vision, may be subdivided into six principal areas: 1. sensing, 2. preprocessing, 3. segmentation, 4. description, 5. recognition, and 6. interpretation.

Artificial intelligence has allowed to implement simple but increasingly sophisticated machine vision techniques for use in many fields, including manufacturing processes. Fundamental principles in physical optics, electronics, and computer science are employed to good advantage in acquiring and processing images, but the interpretation of such images for pragmatic use depends to a great degree on a large and growing number of algorithms and methods, heuristically conceived, rationally extended, and experimentally verified.

Applications in which computer vision can be an essential part of a manipulative task involving industrial robots, or of the control functions in a production process are described.

2 Desired functions of computer vision for sensor - controlled manipulation

Computer vision can be applied in an effective and economic manner to permit industrial robots to deal with imprecisely positioned or unoriented work pieces and assemblies, to compensate for buildup of errors in tolerances, and in general to enable the robot to "fine-tune" the positioning and orientation of its end-effector to adaptively correct for unforeseen changes in the position and orientation of workpieces.

Desired functions for machine vision applicable to sensor-controlled manipulation are following:

- recognition of workpieces/assemblies and/or recognition of the stable state where necessary
- determination of the position and orientation of workpieces /assemblies relative to a prescribed set of coordinate axes
- extraction and location of salient features of a workpiece/assembly to establish a spatial reference for visual servoing
- in-process inspection-verification that a process has been or is being satisfactorily completed.

Computer vision applications for sensor controlled manipulation are following:

* manipulation of separated workpieces on conveyors
* bin - picking
* manipulation in manufacturing
* assembly (in-process inspection, fastening, fitting).

3 Manipulation of Separated Workpieces on Conveyors

There are many instances in which individually separated parts, sub-assemblies, and assemblies are being transported by overhead or belt conveyors from station to station in the factory .The workpieces are more often than not randomly oriented and positioned because this is the least expensive way to transport them. Occasionally they can be quite close to each other and may touch. In those instances in which they are piled more than one layer thick, simple passive mechanical means can usually be devised to unscramble them and essentially maintain one layer. It may be necessary to acquire each workpiece with a manipulator and to transport it for packing in a prescribed order and state in a container, for feeding into another machine with a prescribed position and orientaion, or for sorting in the case of a batch of mixed workpieces.

Two general subclasses can be distinguished-separated workpieces lying stably on a belt, and workpieces hung on hooks.

1. *Separated Workpieces Lying Stably on a Belt*

For many cases in which workpieces are lying stably on a belt and there is an unobstructed view of each separate workpiece (even though they may be touching) it is feasible to apply available simple machine vision techniques to perform one or more of the following:

- identify the workpiece
- determine the stable state of the workpiece
- determine the relative position and orientation of the workpiece.

Successful use of binary visual information depends critically on carefully engineering illumination and control of background. This is necessary to provide a high-contrast image for extraction of a two-dimensional outline representing the shape and major internal features of the workpiece for each stable state. These techniques can be successfully applied on a belt moving with variable speed using the equivalent of flash photography. When sufficient contrast cannot be obtained, more sophisticated picture-processing methods are available.

2. *Workpieces Hung on Hooks*

If the work piece is being transported by an overhead chain conveyor or the equivalent, then the machine vision techniques just discussed will not suffice. Usually the workpiece is crudely supported, requiring three- dimensional information to determine its position and orientation in space. One solution to this problem is to use more expensive supports, guaranteeing unique positioning and orientation in space, and eliminating sway and rotation as much as possible. A more general solution is to add some form of range sensing to existing two-dimensional intensity sensing. Again, the use of structured light or other optical ranging techniques may be good options.

At present, this application of machine vision is most highly developed for dealing with work pieces of the first subclass-that is, those that are, or can be, separated, and that lie stably but unoriented either on moving belts or on a stationary support structure.

For the second subclass of workpieces-those that are hung, partially constrained, on hooks or the equivalent - a considerable research and development effort is needed. Range sensing obtained by passive or active means can help solve this problem in a direct manner, general in application, yielding three-dimensional information on the position and orientation of work pieces in space.

4 Bin Picking

Another common method of transporting and buffer-storing workpieces in factories is in containers or bins. Three major classes can be distinguished.

1. Bin Picking-Workpieces in Completely Random Spatial Organization

The work pieces are jumbled together in a container, sometimes interlocked, randomly positioned and oriented, with no clear unobstructed view of most of the workpieces. This method of transport and buffer storage is the most common in practice, being the least expensive method for rugged workpieces that can withstand some degree of marring or scratching without degradation of quality, performance, or reliability.

2. *Bin Picking-Workpieces Highly Organized Spatially and Separated*

The workpieces have to be handled carefully to prevent damage to delicate details, or they have exposed, finely machined or finished surfaces that should not be scratched or dented. In this class the workpieces are usually arrayed in separate compartments within a bin lined with protective material to prevent damage during transport. Often there are several layers of work pieces in depth in the same bin with protective material between layers.

3. *Bin Picking-Workpieces Partially Organized Spatially and Unseparated*

A third class, quite common in practice, includes workpieces disposed with a degree of organization intermediate between the random arrangement of the first class and the very orderly arrangement of the second class.

The general problem of automating the handling of work pieces is the same for these three classes-workpieces must be acquired one at a time and then presented to some other location with a predetermined position and orientation in space. Applications include sorting and packing, loading work pieces into another machine or process, and presenting parts for assembly. At present one has to rely on sophisticated human visual and tactile capabilities in those instances in which bowl orienters/feeders and other feeders cannot be successfully used due to the size, weight, delicacy, or other properties of the parts. Machine vision, augmented as needed with other sensors and devices, can be successfully applied to a subset of these classes now, with promise of future extension to the rest.

A high level of picture processing and interpretative capability is required for dealing with the completely jumbled and random workpieces. The vision system has to cope with poor contrast, partial views of parts, an infinite number of stable states, variable incident and reflected lighting, shadows, geometric transformations of the image due to variable distance from camera lens to each part, etc.

An approach that finesses many of these problems is to divide the problem of completely disoriented work pieces into two stages. First, remove a few (one or more) of the workpieces at a time from the bin, deposit them with random position and orientation, separated, lying stably on a flat contrasty surface, and then apply known simple machine vision techniques to determine the identity, stable state, position, and orienta- tion of each separated workpiece. Machine vision will thus provide the necessary information for controlling a second and final acquisition by a robot. The method of separation first and then recognition will certainly be acceptable for large, heavy parts for which there is ample time between successive operations.

Simple machine vision techniques appear adequate for the second class, described above, in which separated, partially oriented work pieces are arranged in orderly arrays.

The third class of semi-organized workpieces can be handled by the method of first separating the workpieces and then applying simple machine vision techniques, as described above. Since the workpieces are somewhat aligned and partially organized, separating them is simplified to some degree, with the possibility of reducing the time required for a complete operation.

Bin-picking is an ubiquitous process in almost all factories and represents one of the best candidates for the introduction of sensor-controlled manipulation.

5 Manipulation in Manufacturing processes

In batch production involving discrete parts, a large number of important manufacturing processes cannot be economically automated because of cost of specialized jigs and hard automation production machines is prohibitively high for the small number of work pieces or assemblies in each batch. Programmable automation based on the use of robots has already proved its worth in application to spot-welding (an assembly process) and in automated paint-spraying (a finishing and/or surface protection process). This type of automation is introduced into many production lines.

In paint-spray and similar applications, there still is universal reliance on relatively costly control of workpiece positioning during painting. Since the majority of spray-painting lines do not have specialized conveyors to eliminate the uncertainty in position and orientation, there exists a need for sensors, preferably non-contact, to provide these adaptive corrections. Machine vision in its present implementation is applicable if two-dimensional information suffices. However, in most cases there is again a need for three-dimensional processing to locate a workpiece or assembly in space, thus requiring range information as well as intensity information.

Although spray-painting is a currently popular candidate, similar finishing applications include sand-blasting and spraying of protective chemical coatings on selected areas of the workpieces.

A sub-class of manufacturing processes that have common machine vision requirements includes the application of semi-liquid sealants, deburring and removal of flash from castings and moldings, torch cutting, laser machining, and liquid gasketing. These applications require tool path control along paths that are specified in relation to defined edges, seams, or other features of the workpiece. Due to variations in tolerances and fit, these paths are not precisely predetermined, and therefore each operation is unique within narrow limits, requiring continuous servoing of the tool. Often, for flash removal and sealing, the amount of material to be removed or added, respectively, is variable with position, requiring more elaborate image processing for automatic control of these variables as well as path control. For many of these applications, two-dimensional image processing suffices; with the addition of a proximity sensor, air-pressure sensing, or contact sensing, many contoured work pieces with relatively uncomplicated surfaces can be accommodated. The general case, however, requires three-dimensional servoing, and range information would be most useful.

It should be noted that efficient computational algorithms are available to provide control functions for adaptively correcting the path of a tool carried by a multidegree-of-freedom robot. These algorithms are included in programs that can be executed on- line for:

1. Interpolation-piecewise linear approximations to continuous-path trajectories.
2. Path smoothing-elimination of abrupt changes in the trajectory.
3. Transformations from robot to world coordinate systems and the reverse, including moving-line coordinate systems.

6 Conclusions

Current industrial applications of computer vision range from simple systems that measure or compare to sophisticated systems for part location and inspection. Almost all industrial robots today work with known parts in known positions, and we can see the emergence of programmable automation in which the robot can react to its environment when stimulated by visual and force-touch sensor inputs. Future advances will depend on research now underway in several key areas.

In this paper are selected, described, and analyzed some major classes of problem areas in industry in which successful application of computer vision will have a significant impact on productivity, product quality, and even the mass-production process itself. Further, there are indicated some approaches to possible solutions.

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