A Knowledge - based Approach to Vision Algorithm Design for Industrial Parts Feeder

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Abstract

An expert system for vision algorithm design is presented. It has knowledge bases which include human experts' knowledge about image-processing techniques, and is capable of solving given vision problems. When input images and a goal of analysis are given, it generates executable programs through interactions with user. As a problem-domain, we choose vision algorithms for a parts-feeder system. It determines attitudes of mechanical parts on a conveyer-belt and rejects the inappropriate ones to assembly machines. Production engineers' expertise about selection of features, design of feature measurement procedures, and construction of decision logic are accumulated into knowledge-bases. And the design works for newly appearing parts will be assisted by these knowledge-bases.

1. Introduction

The current image processing and analysis techniques are not almighty, but are able to solve considerable number of practical problems. It, however, cannot be told without image-processing specialists' experience how to use various processing modules and find the optimal solution. Thus, it had better acquire such expertise into a knowledge base and then utilize it in the framework of the so-called expert system. Based on these observations, one of the authors proposed the concept of DIA (Digital Image Analysis)-Expert system several years ago[1]. Since then, much research efforts have been directed towards this subjects[2]. Similar approaches are also found in [3] and [4].

In this paper, we describe an application of this DIA-Expert technique to industrial vision algorithm design. As a practical example, we developed a prototype system which designs parts' attitude discrimination algorithms.

2. Concept of Image-processing Expert System

In what follows, we summarize the concept of 'image-processing expert system' which is proposed by DIA-Expert. The goal of image processing is to attain a highly-abstracted operation such as shape extraction or feature measurement. Function of a image processing module is transformations of image data, for example, from a gray level image to a binary image. And a image processing procedure, which executes a sequence of such transformation, achieves the highly-abstracted operation. When an input image and the goal of analysis are given, we should observe and classify the state of the image, and continue to decompose the goal into subgoals until sequence of executable modules could be found at the terminal level. An image processing expert system proposes the subgoals and assists the user to design the vision algorithm.

By using the framework of knowledge engineering, the knowledge about all the operations, from the highly-abstracted ones to the terminal ones, is represented in terms of the so-called 'frames'. Similarly, the state of the input image and the intermediate resultant images are also described in the frames. On the other hand, sequence of operations and their relations to input/output image data are stored as an augmented tree called Operation-tree. And, the knowledge about the expansion of the tree is described in the form of production rules.

3. Problems of Industrial Application

As an example of the industrial application of our expert system, we consider vision systems for parts-feeder. In order to assemble mechanical parts with an industrial robots, it is expected that a few attitudes out of several stable states of the same parts are accepted by the vision system. Hence, we use the machine vision system shown in **Fig.1**, in which all the parts on the conveyer-belt are observed by TV camera and then the

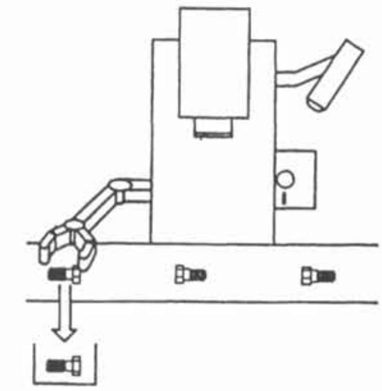


Fig.1 Vision system for parts feeder

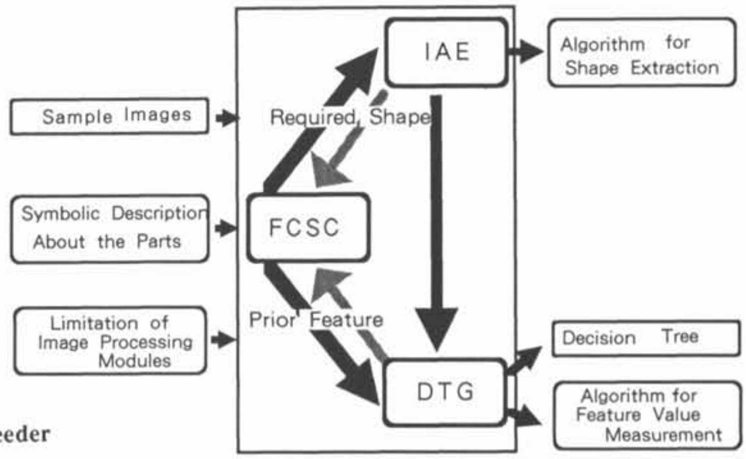


Fig.2 Organization of expert system

inappropriate parts, discriminated through image-processing operations and decision logic, are rejected. Here, it is assumed that the same kind of parts are provided isolatedly in the scene. Though it is not difficult to design an algorithm on each case, huge number of parts newly designed day by day causes troublesome work to the engineers. The expert system assists to design vision algorithms specific to target parts.

The following extensions of the image processing expert system are required to apply them to industrial vision problems as described above.

A. Designing a pattern recognition logic: A framework which is suitable to design the logic for object recognition as well as the image processing procedure is necessary.

B. Designing a robust image processing procedure: Fluctuation of lighting condition, soil on the conveyer-belt, and difference of parts' surface reflectance cause variations of input image data, so that image processing procedure which can measure feature values consistently is required.

4. Organization of Expert System

Problem solving task for a pattern recognition problem consists of three sub tasks: selection of features, design of feature measurement procedure, and construction of decision logic. The first and second task require heuristic knowledge, where the third task can be solved by statistical analysis. Thus, our system has three component systems which cooperate to solve a given problem (**Fig.2**).

Feature Candidates Selection Expert (FCSE) has a knowledge base of features and expects efficiency of each feature to classify *target views* (appearances of the object) using priority factors. A priority factor has a value in [-1,+1], and is manipulated by feature priority rules. Examples of features and feature priority rules are shown in **Table 1** and **Fig.3**. Currently, priority factors are calculated by the same formula as the certainty factors in EMYCIN. The IF-part examines initially given information about object's shape, possible view of the object, restrictions of applicable vision systems, and so on. And, *prior feature* that has the best score and *required shape* that should be extracted to measure the prior feature are selected.

Image-processing Algorithm Expert (IAE) construct a robust image processing procedure to extract the *required shape* using many image samples. The fundamental part of IAE is rule-based goal decomposition same as the general image processing expert system, and the reinforced part will be described precisely in section 5.

Table 1 Efficient shape features

* Area of Whole Object
* Area of Holes
* Compactness
* Elongatedness
* Difference of Areas by Changing Threshold
* Moment Features
* Euler Number
* Perimeter Length
* Angle Features
etc.

IF for each ***view** in target-views,
attitude-relation of ***view** is reverse
and ***feature** is symmetry-invariant
THEN update priority-factor of ***feature** with -1

Fig.3 Example of feature priority rules

Decision Tree Generator (DTG) measures feature values of all sample images, based on the *prior feature* selected by FCSE and image processing procedure constructed by IAE. And it determines the threshold values to distinguish the attitudes and makes a node of the decision tree. Here, we use a decision tree as a decision logic. It, however, is not difficult to use statistical pattern recognition techniques instead of decision tree by exchanging DTG to another subsystem.

5. Construction of Robust Vision Algorithms

It is necessary that many samples, selected to represent a variety of input conditions, should be used to obtain a stable solution in working environments. An efficient way to construct robust algorithms using sample images is described below.

The sample images are used in *multi-image verification/single-image modification* (MIV/SIM) cycle; First, IAE constructs a initial image-processing procedure with a certain sample image data. Second, this procedure is applied to all sample images and the resultant images are examined in MIV process:. If any sample image is not processed adequately, SIM process with this image is activated to correct the procedure. The image for which the procedure cannot be corrected is extinguished from the sample images and considered to indicate improper input condition. After the procedure is modified, the MIV process is re-activated.

The final image processing procedure is designed through iteration of this MIV/SIM cycle. In the MIV/SIM cycle, the MIV process is the most time-consuming process, so that we make it automatize as follows; Previous to the cycle, the design work proceeds using *reference image data* (selected from sample images) of each class (*view*), and the processing result which is certified by the user is registered as an *extracted shape models* of each class. In the MIV process, a processing result of each sample image is compared to the extracted shape model by calculating certain features. Only if the difference of the feature values is greater than a predetermined threshold value, user has to answer whether the result is proper or not.

Modification is done in two steps: finding improper operations and applying modification rules. This kind of rules select possible modification methods which result in addition of complementary operations or correction of parameters.

6. Experimental System

Based on the above consideration, we developed a prototype system for designing parts attitude distinction procedures.

The initial inputs to the system are

* image data of all stable attitudes of the target parts taken in some different input conditions, considering the actual environment, and
* symbolic description about the parts such as existence of hole in the parts, symmetry of the parts' shape, and relation of attitudes (obverse and reverse).

The outputs of the system are decision tree logic as shown in **Fig.4**, and image processing procedures to extract the shape as shown in **Fig.5**.

The user of the system is assumed to be a production engineer in factories, who doesn't have enough knowledge about image-processing. And the knowledge-base would be updated by specialists of production techniques.

This system works on Symbolics lisp machines and the knowledge processing part of the system is implemented in Uranus (an extended Prolog processor, Prolog/KR), where image processing modules are written in Fortran.

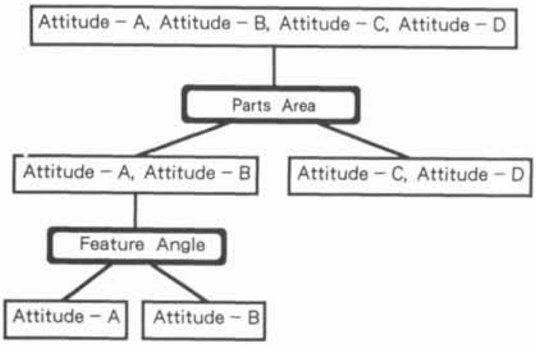


Fig.4 Decision tree

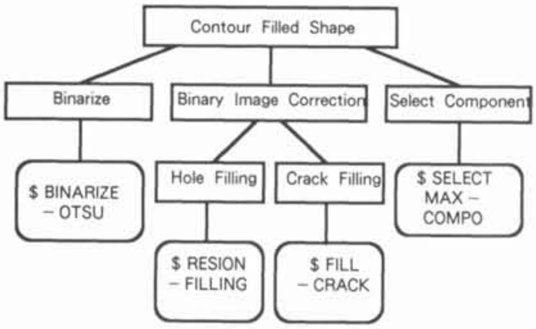
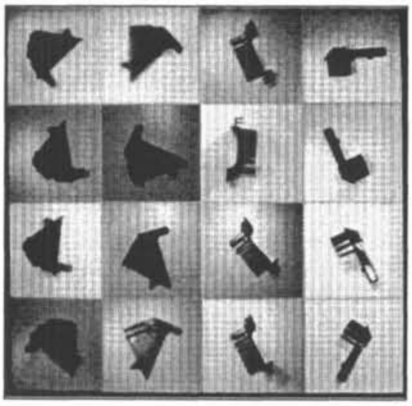
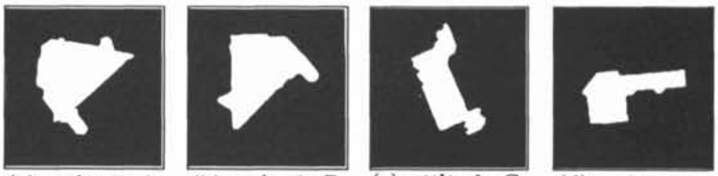


Fig.5 Operation tree





(a) attitude-A (b) attitude-B (c) attitude-C (d) attitude-D
Fig.7 Extracted shape models

Fig.6 Sample images

Fig.8 An example of inadequate result

Fig.9 Angle features

An example of the system behavior is described as follows:
The parts shown in **Fig.6**. has four stable attitudes (A,B,C,D) and the objective attitude is A. After the initial inputs were given, FCSE selected 'Parts Area' as the *prior feature* and 'Contour Filled Region' as the *required shape*. Then IAE proposes image processing modules to extract 'Contour Filled Region'.

For instance, binarization with automatic threshold determination was selected as the first operation, and the resultant image was displayed so that the user can examine it. As the user found no problems in that figure, the system proceeded to next operations. (If any problems had occurred, other alternatives would have been tested.) Thus, the initial procedure was constructed. This procedure was applied to the *reference images* of all attitudes. In this case, user confirmed all the resultant images (**Fig.7**) are adequate, so that they were registered as *extracted shape models*. IAE proceeded to MIV process and found suspicious results shown in **Fig.8**. The user denoted the result was improper. Then, intermediate results was displayed and 'Binary Image Correction' was selected to be modified by the user's indicating improper resultant images.

After questioning and answering to evaluate modification rules, 'Crack Filling' was added to the procedure (**Fig.5**). Since the modified procedure caused no error in MIV process, DTG calculated area of all sample images and construct a decision node as shown in **Fig.4** .

Then, *target attitudes*, which is used as the *target views*, was changed to (A,B). FCSE was re-activated by the change of *target attitudes*. As B is reverse to A, the priority factors of features such as moment was decreased, and 'angle between the nearest and the most distant points on contour line from center of gravity' (**Fig.9**) was selected. Here, the *required shape* didn't change, so that only DTG was reactivated. Finally, a decision tree shown in **Fig.4** was constructed.

7. Conclusion

In this paper, we present an image processing expert system applied to the industrial vision algorithm design. By employing feature-level expert modules, FCSE and DTG, in addition to the operation level expert module IAE, our system may find the solution of pattern recognition problems.

Inference on feature effectiveness raises the efficiency of problem solving process. MIV/SIM cycle used in IAE utilizes many sample images so that the generated procedure brings consistent results to the images taken in fluctuating input conditions. And automated processing results verification with the *extracted shape models* reduces laborious user-interaction considerably.

Currently, the system doesn't employ knowledge in as to converge modification process. And, when the modification causes other verification failures, the user must determine if he tries further to modify the procedure or gives up modification and ignore the sample image. In the future research, we will have to utilize knowledge, such as how to determine the possibility of modification or how to select proper operations in contradictory situations of sample images, to proceed modification process efficiently.

Reference

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