KNOWLEDGE-BASED CONFIGURATION OF IMAGE PROCESSING ALGORITHMS

U. ROST, H. MÜNKEL
Institut für Theoretische Nachrichtentechnik, Universität Hannover
Appelstr. 9a, 30167 Hannover, Germany
http://www.tnt.uni-hannover.de

In the last 10–15 years image processing systems have been integrated into industrial manufacturing processes in various ways, for example within the areas of process control and quality assurance. Most of these systems use highly specialized algorithms which suffer from a lack of flexibility against changes within the process environment or the given task.
In this paper we present SOLUTION, a knowledge-based system that is able to overcome this problem by automatically adapting the used image processing algorithm to varying needs. SOLUTION accepts a task description presented in high level terms, configures an adequate sequence of image processing operators and adapts their parameters. SOLUTION therefor uses expert knowledge formulated explicitly by rules.
The results presented here refer to the general task of creating an optimal contour-image that can be further processed by subsequent high-level routines. Examples are taken from real world applications in the areas of medical and industrial image processing.

1 Introduction

In the last 10–15 years image processing systems have begun to play an increasing role within many industrial manufacturing processes [1]. These systems are used to observe or even control the manufacturing process or to inspect the final product to test whether a sufficient quality has been reached.

The problem that arises lies within the lacking flexibility of these systems which are mostly designed to fulfill exactly one task. Even slight changes in the environment can cause the used algorithm to fail to produce the expected result. In this case recalibration is needed. Bigger changes often require a complete reprogramming of the system. Because of the complexity of these systems only an image processing expert is able to do the necessary changes. Of course this can be a very expensive and time consuming task.

SOLUTION (Solution for a Learning Configuration System for Image Processing), the system that we describe in this paper overcomes this problem by two means:

First at all it strictly separates the task-specific part of the problem to solve from the image processing part. The user can specify the task using natural spoken terms which refer to the appearance of the resulting image and some general requirements. Thereby he doesn't need to know how the result can be achieved.

Second SOLUTION which is based on the CONNY system [2,3], uses explicitly formulated expert knowledge to carry out the image processing part of the problem. SOLUTION includes a set of image processing operators and performs a knowledge-driven choice to select appropriate operators out of this set, to combine them and to adapt their parameters. [a]

2 The structure of SOLUTION

The basic idea behind SOLUTION was to create a system that acts similar to an image processing expert. That means, depending on a given task, the system should be able to select a sequence of appropriate image processing operators and to adjust the parameters they contain, so that the result has a defined quality.

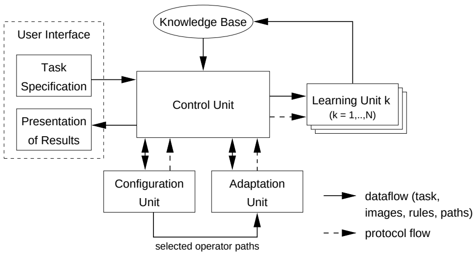


Figure 1: Structure of SOLUTION

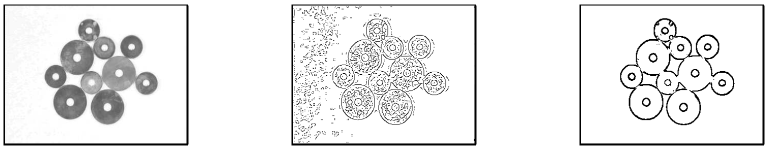
Figure 1 shows the general structure of SOLUTION. The control unit is responsible for the coordination of all system activities. It provides all other modules with the information they need and controls the data and protocol flow.

The image processing task can be specified via a graphical user interface which also presents the results that have been achieved. The task itself consists of an explicit and an implicit part. First of all the user has to define explicitly some properties which the resulting image processing algorithm and the output images are expected to have. The implicit part of the task specification is given by a couple of properties of the class of images that has to be processed and which are measured in a test image that the user has to provide.

The configuration unit takes the information gained from these measurements to select appropriate image processing operators. The operators are combined in every way that leads to an image processing path which is formally correct. Their parameters are initialized according to the included operators using the measured properties of the input image. The resulting paths are then passed to the adaptation unit.

In contrast to the configuration the adaptation is an iterative process performed separately for each path. The parameters included in each path are

[a] A more detailed description of the system can be found at http://www.tnt.uni-hannover.de/project/kbs/solution/



Input image

Thickness: not
Distinctness: weak
Granulation: strong

Thickness: average
Distinctness: strong
Granulation: not

Figure 2: Example contour images with selected sensor values

corrected stepwise until the properties of the resulting image match the according task specifications.

As it is very difficult and time consuming to create manually a complete and consistent rulebase that suits the needs of all possible tasks, SOLUTION contains some learning units which support the process of building and maintaining different parts of the rulebase. The units that have been developed until now are able to learn adaptation rules by goal-directed experimentation and by a special knowledge-based genetic algorithm. These algorithms are described in [4] and are not discussed further in this paper.

3 Sensors

The sensors used in SOLUTION are procedures that are able to measure the image properties needed to make decisions about the choice of operators and the adaptation of the parameters. All sensors are assigned to one of two general classes which represent the kind of image they work on. The first class contains all sensors that measure properties of the input image, e.g. the mean noise, the amount of disturbances, the edge height or the contour width of selected lines in the image. The second class comprises sensors which measure features of the resulting image. The sensors needed for the special purpose of evaluating contour images form a subclass of it. Figure 2 gives three examples for contour sensors and the values processed for two different output images.

4 Configuration

The configuration unit is responsible for the selection of appropriate image processing operators and for combining them to image processing paths. Furthermore it initializes the parameters included in the operators.

All decisions about the choice of operators and the settings of the parameters depend on the properties of the input image and some requirements specified in the task description. The values of these properties such as the noise, the amount of disturbances, the height and the contour width of the edges in the image are measured with the help of the user. The values are then quantized to one of the values "not", "weak", "average" and "strong". Examples for the resulting task specifications are "the noise in the image is weak" and "the contour width of the edges is average".

In addition to this there are some general requirements for which the user has to supply priority values like "necessary", "important", "unimportant" or "don't care". They refer to some general constraints as for example the need to get a short processing time. An example for a resulting specification is that "it is necessary to have a short processing time".

The selection of operators is performed as a rule inference process where each rule consists of a condition part including one or more of the specifications described above and an action part which removes exactly one operator from the list of possible operators that are known to the system. An example for such a rule is:

if the noise is <= weak **and**
a short processing time is >= important
then don't take the Nonlinear Laplace operator

The remaining operators are taken to construct image processing paths. For that the operators are combined such that formally correct paths are obtained. This process is constrained by the working principles and the purpose of the operators involved (e.g. preprocessing or contour enhancement).

The parameter initialization depends on the properties of the input image specified in the task description and on the operators used in a certain path. The knowledge needed for that is also encoded as rules.

5 Adaptation

The adaptation process imitates the strategy of an image processing expert who knows what the resulting image has to look like. He adjusts the parameters of an operator path stepwise by changing some selected parameter values. According to the effects he decides whether further changes have to be made.

Figure 3 shows the adaptation process. The input needed is received by the control unit and consists of the image to be processed, the initialized path P_0, created by the configuration unit and a global goal. This goal includes all task specifications referring to the properties which the resulting (contour) image is expected to have and which can be measured by the sensors described in section 3. Each part of the global goal refers to exactly one sensor and specifies which value it should reach, in which way and with which priority, e.g. that “it is necessary that the fragmentation of the detected contours is equal to weak”.

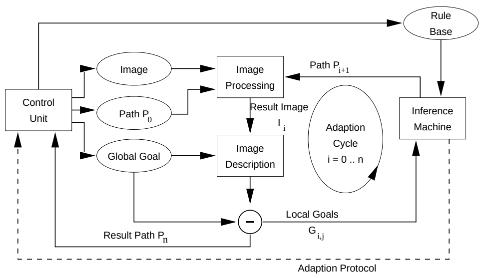


Figure 3: Adaptation of parameters

First the path P_0 is processed and an output image I_0 is created. This image is evaluated by the sensors and the measured values are compared to the values defined in the global goal. From each difference a local goal is created which describes a sensor change that has to be achieved to reach the global goal. If for example the fragmentation of the lines is average but according to the global goal it should be weak, a local goal is created that states that “the fragmentation should be decreased weakly”.

The inference process is carried out using rules which represent the knowledge of an image processing expert who knows which parameters have to be changed to fulfill one or more local goals dependent on what the image looks like. An example adaption rule is given below:

if the fragmentation should be decreased weakly **and**
the thickness is less than strong
then increase the threshold of the Binarize operator weakly

The parameter changes performed lead to the creation of a new path $P_{i+1}(i = 0, \ldots, n-1)$ which is used in the next step of the adaptation loop. The process continues until the difference to the global goal is small enough to ensure a satisfactory result which is given back to the control unit.

6 Results

The results presented here have been achieved for the task of extracting the contours of some objects from grey-level images. Two kinds of test images were used. The first group depicts industrial objects lying on a light background. These images contain very little noise and nearly no disturbances. The second group shows x-ray images of a human knee in which a knee joint endoprosthesis was implanted. The images of this group were taken to test the robustness of the adaptation concerning varying types of images with different properties.

SOLUTION knows 10 operators that can be used to generate 40 different paths to create a contour image. Due to the requirements implied by the task and the properties of the first group of images only four different paths remained after the configuration process.

Figure 4 shows the results that have been achieved for one of these paths with two different images. This path contains two adaptable parameters. The adaptation performed took between 8 and 12 steps and 4 different rules were used. At the left side the input images are shown, in the middle the resulting images of the paths P_0 can be seen. The right image depicts the resulting image achieved after the adaptation had finished. In all cases the task was fulfilled.

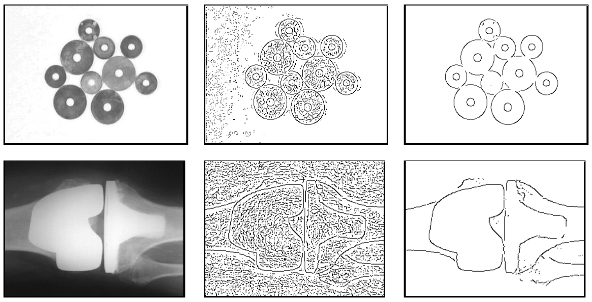


Figure 4: Results for the images lockwashers and knee

The images show clearly that the quality of the contour images has been improved significantly with respect to the defined goals. Even a human expert is hardly able to achieve a better result using the given image processing operators.

Acknowledgements

The project has been supported by the Deutsche Forschungsgemeinschaft.

References

1. T.S. Newman, A.K. Jain (Ed.): “A Survey of Automated Visual Inspection”, Computer Vision an Image Understanding, Vol.61, No.2, March 1995, pp. 231–262.
2. C.-E. Liedtke, A. Blömer, T. Gahm: “Knowledge-Based Configuration of Image Segmentation Processes”, International Journal of Imaging Systems and Technology, Vol.2, 1990, pp. 285–295.
3. C.-E. Liedtke, A. Blömer: “Architecture of the Knowledge Based Configuration System for Image Analysis Conny”, Proc. of the 11th International Conference on Pattern Recognition, The Hague, Vol.1, September 1992, pp. 375–378.
4. U. Rost, P. Oechtering: ”Knowledge-Based Genetic Learning”, Proc. of the Sixth Scandinavian Conference on Artificial Intelligence (SCAI 97), August 1997, Helsinki, Finland, pp. 107–118.