Category: Multimedia Technology

Image Segmentation in the Last 40 Years

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INTRODUCTION

Image segmentation is an important image technique well known by its utility and complexity. To extract the useful information from images or groups of images, an inevitable step is to separate the objects from the background. Segmentation is just the right process and technique required for this task. Image segmentation is often described as the process that subdivides an image into its constituent parts and extracts those parts of interest (objects). It is one of the most critical tasks in automatic image analysis, which is at the middle layer of image engineering. Image engineering (which is composed of three layers from bottom to top: (1) image processing, (2) image analysis, and (3) image understanding) is a new discipline and a general framework for all image techniques (Zhang, forthcoming).

The history of segmentation of digital images using computers can be traced back to 40 years ago. In 1965, an operator for detecting the edges between different parts of an image, Roberts operator (also called Roberts edge detector), was introduced and used for partition of image components (Roberts, 1965). Since then, the field of image segmentation has evolved very quickly and has undergone great change (Zhang, 2001a). In this article, after an introduction and explanation of the formal definition of image segmentation as well as three levels of research on image segmentation, the statistics for the number of developed algorithms in these years are provided; the scheme for classifying different segmentation algorithms is discussed; and a summary of existing survey papers for image segmentation is presented. All these discussions provide a general picture of research and development of image segmentation in the last 40 years.

BACKGROUND

Formal Definition of Image Segmentation

A formal definition of image segmentation, supposing the whole image is represented by R and R_i, $i = 1, 2, \ldots, n$ are disjoint nonempty regions of R, consists of the following conditions (Fu & Mui, 1981):

$$\bigcup_{i=1}^{n} R_i = R; \quad (1)$$

For all i and j, $i \neq j$, there exits $R_i \cap R_j = \varnothing$; (2)

For $i = 1, 2, \ldots, n$, it must have $P(R_i) = TRUE$; (3)

For all $i \neq j$, there exits $P(R_i \cup R_j) = FALSE$; (4)

where $P(R_i)$ is a uniformity predicate for all elements in set R_i and $\varnothing$ represents an empty set.

The following condition is also important for segmentation and is often included in the conditions for the formal definition (Zhang 2001a):

For all $i = 1, 2, \ldots, n$, R_i is a connected component. (5)

In the aforementioned conditions, each of them has particular meanings. The condition (1) points out that the union of segmented regions could include all pixels in an image. The condition (2) points out that the different segmented regions could not overlap each other. The condition (3) points out that the pixels in the same regions should have some similar properties. The condition (4) points out that the pixel belonging to different regions should have some different properties. The condition (5) points out that the pixels in the same region resulted from segmentation are connected.

Three Levels of Research on Image Segmentation

Though many efforts have been devoted to the research of segmentation techniques, there is no general theory for image segmentation, yet. Therefore, the development of segmentation algorithms has traditionally been an ad hoc process. As a result, many research directions have been exploited, some very different principles have been adopted, and wide varieties of segmentation algorithms have appeared in the related literatures. It was noted by many people that none of the developed segmentation algorithms are generally applicable to all kinds of images and different algorithms are not equally suitable for a particular application (Zhang, 2006).

With the increase of the number of algorithms for image segmentation, how to evaluate the performance of these algorithms becomes indispensable in the study of segmentation. Considering the various modalities for acquiring different images and the large number of applications requiring image segmentation, how to select appropriate algorithms for segmentation turns into an important task. A number

of evaluation techniques have been proposed. For those published in the last century, see survey papers by Zhang (1996) and Zhang (2001b).

While the evaluation of segmentation techniques has gained more and more attention, with numerous evaluation methods frequently designed, how to characterize the different existing methods for evaluation has also attracted some interest in recent years (Zhang, 2001a). In fact, different evaluation criteria and procedures, their applicability, advantages, and limitations need to be studied carefully and systematically.

According to the previous discussion, the research for image segmentation is carried out in three levels (Zhang, 2006). The first one and the basic one is the level of algorithm development. The second one is the level of algorithm evaluation. The third one is the level of systematic study of evaluation methods. This present article will mainly concentrate on the first level.

MAIN THRUST

The current study focuses on three points:

1. A worldwide statistics about the number of segmentation algorithms already developed.
2. A method for classifying different segmentation techniques into groups.
3. A general overview of survey papers for segmentation, published in the last 40 years.

Amount of Developed Segmentation Algorithms

Over the last 40 years, the research and development of segmentation algorithms are going on and making very rapid progress. A great number of segmentation algorithms have been developed and this number continually increases each year. Table 1 gives a list of the numbers of records (for every 5 years) found in EI Compendex (the most comprehensive bibliographic database of engineering research available today, see http://www.ei.org) by using the term *image segmentation* to search only in the field of "Subject/Title/Abstract."

Figure 1 gives a plot of the number of records found, together with a tendency curve obtained by using the third order polynomial. It is interesting to note the very fast increasing rate (an exponential raise) for the number of papers published. It is also interesting to note there is not any sign for the slowdown of augmenting.

A Classification of Segmentation Algorithms

With so many publications appearing in the literature and so many segmentation algorithms being developed, the classification of various algorithms for image segmentation becomes an essential task in studying image segmentation.

A classification of algorithms into groups, in principle, is a problem of set partition into subsets. With reference to the conditions for the definition of segmentation (Fu & Mui, 1981), it was believed that the resulted groups after

Table 1. List of records found in EI compendex

1965-1969	1970-1974	1975-1979	1980-1984	1985-1989	1990-1994	1995-1999	2000-2004	Total
10	20	233	680	1499	3423	7665	12727	26257

Figure 1. Number of records and the tendency of development in the last 40 years