Half Century for Image Segmentation

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INTRODUCTION

Image (and video) segmentation is an important image technique, and is often described as the process that subdivides an image (or a clip of frames) into its constituent parts and extracts those parts of interest (objects). It is well known by its utility, since for extracting the useful information from images or a group/sequence of images, to separate the objects from background is an inevitable step/task. It is also well known by its complexity, as there is no general theory for image segmentation, yet. Therefore, the development of image segmentation techniques is still an *ad hoc* process.

Image segmentation is one of the most critical tasks in automatic image analysis, which is at the middle layer of image engineering (IE). Image Engineering (which is composed of three layers from bottom to top: image processing, image analysis and image understanding) is a new discipline and a general framework for all image techniques (Zhang, 2008d).

According to the statistics gathered from a yearly bibliography survey on image engineering (Zhang 2013), the journal publication on image segmentation is ranked the first among the current 16 groups/branches of research techniques of image engineering. The comprehensive survey has been made consecutively for 18 years, and the totally involved papers are more than 40000, in which 8243 are related to the different technique groups of image engineering. The statistics for the distribution of these papers in each group are listed in Table 1. It is seen that the group of image segmentation is the one that attracts the most attentions and achieve the most results among a complete list of technique groups.

In this article, after an introduction about 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 representations and discussions provide a general picture of research and development of image segmentation in the last 50 years.

BACKGROUND

The history of segmentation of digital images using computers can be traced back to 50 years' ago. The earliest proposed method for image segmentation, which is a global thresholding technique, should be the

Table 1. Journal papers in different technique groups

No	Technique Group	# of Papers	No	Technique Group	# of Papers
1	Segmentation and edge detection	1238	9	Content-based image retrieval	347
2	Enhancement and filtering	974	10	Reconstruction from projections	303
3	Coding/decoding	896	11	Analysis and feature measurement	287
4	Object extraction and recognition	832	12	Object representation and description	233
5	Registration, matching and fusion	810	13	3-D modeling and scene recovery	231
6	Biometrics	643	14	Multiple-resolution processing	158
7	Watermarking, and information hiding	599	15	Spatial-temporal technology	90
8	Capturing and storage	523	16	Image perception and interpretation	79

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"p-tile" method (Doyle, 1962). This method needs to know the percentage (*p*%, the name comes) of object pixels in the whole image, and chooses the gray level as threshold that could map *p*% pixels to the object region. As an example, suppose one image consists of a lighter object on a darker background, then the threshold level should separate the whole pixels into two parts: one with *p*% pixels for the object while another with (100 – *p*)% pixels for the background. In digital images, the exact percentage might not be achieved, so a most closed percentage could be selected.

Since then, the field of image segmentation has evolved very quickly and has undergone great change (Zhang, 2001a; Zhang, 2006). The cumulative effort makes this field becoming the most active and most fruitful one in all fields of image engineering, as demonstrated by Table 1.

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 (Zhang, 1996; Zhang, 2001b), while for those published in this century, see (Zhang, 2008a).

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 (Zhang, 2006).

According to the above discussion, the research for image segmentation is carried on 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.

GENERAL PROGRESS STATUS

After 50 years of development, the current progress status of image segmentation could not be totally covered by only a few of pages. Instead, three aspects are presented to give a general idea:

1. A worldwide statistics about the number of segmentation algorithms already developed.
2. A general scheme for classifying different segmentation techniques into groups.
3. An overview of survey papers for segmentation, published in the last 50 years.

Amount of Developed Segmentation Algorithms

Over the last 50 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 2 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.

Table 2. List of records found in EI Compendex

Period	62-66	67-71	72-76	77-81	82-86	87-91	92-96	97-01	02-06	07-11	Total
Number	7	8	61	353	1036	2086	4901	9672	18425	37098	73647

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 numbers of record found.

It is interesting to note the very fast increasing rate (an exponential raise) for the number of papers published, especially in the last 30years, in which the "Moore law" could be applied. For image segmentation, it could be stated: the publications are seemed to double every 5 years.

The fast growing for the number of publications in image segmentation are due to several reasons. First, there is no general theory for image segmentation, as indicated above. Researchers have used different mathematic theories to treat this problem. Second, there exit various applications that require specific segmentation algorithms. Thirdly, with the progress of investigation, many existing techniques have been revisited for improvement and comparison (e.g., Xue & Zhang, 2012).

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 an appropriate classification of segmentation algorithms, according to the process and objective, should satisfy the following four conditions (Zhang, 1997):

1. Every algorithm must be in a group.
2. All groups together can include all algorithms.
3. The algorithm in the same group should have some common properties.
4. The algorithm in different groups should have certain distinguishable properties.

Classifications of algorithms are performed always according to certain classification criteria. The first two conditions imply that the classification criteria should be suitable for classifying all different algorithms. The last two conditions imply that the classification criteria should determine the representative properties of each algorithm group.

Taking the above conditions in mind, the following two criteria turn up to be suitable for the classification of segmentation algorithms. The first is the discontinuity or similarity of pixel property; the second is the sequential or parallel of processing strategy. All segmentation algorithms can be classified into four groups, namely G1, G2, G3, and G4, according to these two criteria. The results are shown in Table 3.

The classification from Table 3, is just made in the top level. For each class, or even sub-class, more deeply classification would be required. For example, thresholding techniques (a sub class of G3) can be further classified into point-dependent, region-dependent and coordinate-dependent, according to the information used and support region scale in threshold selection. More details see (Zhang, 2009).

Figure 1. Number of records and the tendency of development in the last 50 years

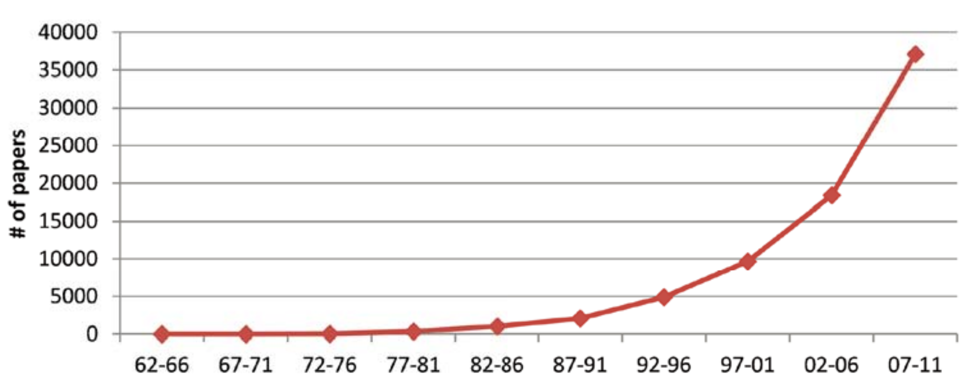

Table 3. General classification of segmentation algorithms

Classification	Edge-Based (Discontinuity)	Region-Based (Similarity)
Parallel Process	**G1:** Edge-based parallel process	**G3:** Region-based parallel process
Sequential Process	**G2:** Edge-based sequential process	**G4:** Region-based sequential process

Overview of Survey Papers

Along with the development of image segmentation algorithms, a number of survey papers for general image segmentation algorithms have been presented in the literature over the last 50 years (Zhang, 2008b).

If partitioning the last 50 years into 5 decades, it is interesting to note that most of these survey papers are dated in the second and third decades. The reason for no survey paper published in the first decade is that the research results were just cumulated in that period (some important works for this period have been indicated in the survey papers published in the second period). The reason for no survey in the last two decades could be attributed to the factor that so many techniques have already been presented, thus a comprehensive survey becomes less feasible.

Though no general survey for the whole scope of image segmentation has been made in the last 20 years, some specialized surveys are nevertheless published in recent years. These survey papers can be classified into two sub-categories.

1. Survey Papers Focused on Particular Group of Segmentation Algorithms

Many segmentation algorithms have been developed by using certain mathematical/theoretical tools, such as fuzzy logic, genetic algorithm, neural network (NN), pattern recognition, wavelet, etc.; or based on some unique framework, such as active contour model (ACM), thresholding, watershed, etc. Some surveys for algorithms using the same tools or based on the same frameworks have been made. The following gives some examples.

Considering that the fully automatic methods sometimes would fail and produce incorrect results, the intervention of a human operator in practice is often necessary. To identify the patterns used in the interaction for the segmentation of medical images and to develop qualitative criteria for evaluating interactive segmentation method, a survey of computational techniques for human–computer interaction in image segmentation has been made (Olabarriaga & Smeulders, 2001). This survey has taken into account the type of information provided by the user, how this information affects the computational part, and the purpose of interaction in the segmentation process for the classification and comparison of a number of human–machine dialog methods.

Algorithms combining edge-based and region-based techniques will take the advantage of the complementary nature of edge and region information. A review of different segmentation methods, which integrate edge and region information, has been made (Freixenet, Munoz, & Raba, 2002). Seven different strategies to fuse such information have been highlighted.

Active shape model (ASM) is a particular structure for finding the object boundary in images. Under this framework, various image features and energy functions as well as different search strategies can be used, which makes a wide range of ASM algorithms. A number of these variations for segmentation of anatomical bone structures in radiographs have been reviewed in (Behiels, et al., 2002).

Thresholding technique is a very popular, relative simple and fast technique. A survey of thresholding methods with a view to assess their performance when applied to remote sensing images has been made recently (Marcello, Marques & Eugenio, 2004). Some image examples are taken from oceanographic applications in this work.

More recent surveys in this category include using fuzzy clustering (Naz, Majeed & Irshad, 2010), fuzzy logic, neural networks and genetic algorithms (Karasulu & Balli, 2010), fuzzy-watershed (Rashwan, et al., 2009), soft computing (Senthilkumaran & Rajesh, 2009), transition region extraction (Yan and Sun, 2008), and unsupervised methods (Zhang, Fritts & Goldman, 2008).

2. Survey Papers Focused on a Particular Application Area of Image Segmentation

Image segmentation has many applications. For each application, a number of segmentation algorithms could be developed. For certain particular application areas, some surveys have been made.

In medical imaging applications, image segmentation is used for automating or facilitating the delineation of anatomical structures and other regions of interest. A survey considering both semi-automated and automated methods for the segmentation of anatomical medical images has been made (Pham, Xu, & Prince, 2000). The advantages and disadvantages of these methods for medical imaging applications are also discussed and compared.

While video could be considered as a particular type of general images, its segmentation is just an extension of image segmentation. For video data, the temporal segmentation is used for determining the boundary of shots. A survey has made for techniques that operate on both uncompressed and compressed video stream (Koprinska & Carrato, 2001). Both types of shot transitions: abrupt and gradual transitions are considered. The performance, relative merits, and limitations of each of the approaches are comprehensively discussed.

For temporal video segmentation, except the ability and correctness of shot detection, the computation complexity is also a criterion that should be considered, especially for real-time application. A review of real-time segmentation of uncompressed video sequences for content-based search and retrieval has been made (Lefèvre, Holler, & Vincent, 2003). Depending on the information used to detect shot changes, algorithms based on pixel, histogram, block, feature, and motion have been selected.

Vessel extraction in bioengineering is essentially a segmentation process. A survey for related algorithms has been made (Kirbas & Quek, 2003). Six groups of techniques proposed for this particular application are involved: (1) pattern recognition techniques; (2) model-based approaches; (3) tracking-based approaches; (4) artificial intelligence-based approaches; (5) neural network-based approaches, and (6) miscellaneous tube-like object detection approaches.

In many vision applications, moving shadows must be detected. Moving shadows can be considered as object in video streams and the detection of moving shadows is a video segmentation problem. A survey has been made for four classes of techniques (2 statistical ones and 2 deterministic ones) designed especially for detecting moving shadows (Prati, et al., 2003).

Some more recent survey papers are specialized in content-based visual information retrieval (Zhang, 2008c), left ventricular segmentation (Deopujari, Dubey & Mushrif, 2011), license plate character segmentation (Wang, et al. 2011), ultrasound image segmentation (Noble & Boukerroui, 2006), and volumetric image segmentation (Puranik & Krishnan, 2010).

SEGMENTATION EVALUATION

As mentioned in the above, with the large number of algorithms for image segmentation developed, the performance evaluation of these algorithms becomes indispensable. Early works in this direction could be traced back to the years of 1970 (e.g., Fram & Deutsch, 1975; Yasnoff, Mui & Bacus, 1977), and since then considerable efforts have been contributed to this area (Zhang, 2008a).

Segmentation evaluation methods can be classified into analytical methods and empirical methods (Zhang, 1996). The analysis methods treat the algorithms for segmentation directly by examining the principle of algorithms while the empirical methods judge the segmented image (according to predefined criteria or comparing to reference image) so as to indirectly assess the performance of algorithms. Empirical evaluation methods can be classified into goodness method group and discrepancy method group (Zhang, 1996). They use different empirical criteria for judging the performance of segmentation algorithms. The goodness method can perform the evaluation without the help of reference images while the discrepancy method needs some reference images to arbitrate the quality of segmentation.

The empirical evaluation is practically more effective and usable than analytical evaluation. Recent advancements for segmentation evaluation are mainly made by the development of empirical evaluation techniques (Zhang, 2008a). These new research works can be classified into three groups: those based on existing techniques, those made with modifications of existing techniques, and those used dissimilar ideas than that of existing techniques. In general, most results are obtained in the first two groups; very new approaches are still required.

There are many criteria used in segmentation evaluation, except some analytic criteria (such as), most criteria are for empirical evaluation and could be grouped into four classes: the number of mis-segmented pixels, the position of mis-segmented pixels, the number of objects in the image, and the feature values of segmented objects (Zhang, 2008a). Some other special criteria are in nature related to these classes. For example, the criterion moderate number of regions is related to the number of objects in the image; the criterion region consistency is related to both the number of mis-segmented pixels and the position of mis-segmented pixels; the criterion symmetric divergence (cross-entropy) could be considered as a special feature of segmented objects; and the criterion correlation between original image and bi-level image should be based on the feature values of segmented objects.

On the other side, these criteria also show the focus on segmentation results and the problems encountered in the development of image segmentation. From a visual inspection point of view, the excellence of image segmentation should be easily judged by the number of mis-segmented pixels, the position of mis-segmented pixels, and the number of objects in the image. From the image analysis point of view, the quality of image segmentation should be quantitatively measured by the feature values of segmented objects. It is clear that depending on the context of segmentation, different segmentation algorithms should be developed to fulfill the purpose of segmentation tasks.

FUTURE RESEARCH DIRECTIONS

Though many progresses have been made for the past half century, the subject of image segmentation still needs additional study efforts. Based on the survey made above, a few further research directions are indicated as follows:

1. Incorporating human factors

Since image segmentation is a process at the middle layer of image engineering, it is influenced strongly by human factors. It seems that the assistance of humans, who are knowledgeable in the application domain, will remain essential in any practical image segmentation method. Incorporating high-level human knowledge algorithmically into the computer should be a challenge in the future.

2. Introducing more mathematical models and theories

The introduction of various mathematical models and theories into the research of image segmentation has proved to be quite effective. Since many novel models and theories have been invented and/or created in these years, introducing them into the research on image segmentation would be promising. One example is the incorporation of machine learning framework (e.g., Shen & Zhang, 2009).

3. Enlarging the scope of applications

Though no general theory for segmentation exists, researches on segmenting different particular images from numerous applications have made many progresses. As a lots of new applications still call up for segmentation, developing the suitable algorithms for those new areas would have great potential, either from the point of view technique developments or from the point of view of image applications.

4. Evaluating the developed techniques

With so many developed segmentation algorithms, how to evaluate them in hand, how to judge their performance as well as how to select them for particular applications get more and more attention. However, efforts in this direction are needed to be improved, and more advances are expected (Zhang 2008a). Performing evaluation in different semantic levels would be a promising direction (Desurmont, 2005).

CONCLUSION

An overview of the development of image and video segmentation in the last 50 years is provided with emphasis on showing the number of segmentation algorithms already developed, on describing the techniques for classifying these algorithms and on analyzing the survey papers for image segmentation. With such an expansive overview, readers should perceive a general idea about the half-century progresses of research and application on image segmentation.

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ADDITIONAL READING

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KEY TERMS AND DEFINITIONS

Active Contour Model: Active contour model is a sequential technique for image segmentation. Given an approximation of the boundary of an object in an image, an active contour model can be used to find the "actual" boundary by deforming the initial boundary to lock onto features of interest within in this image.

Clustering: Clustering is also called unsupervised learning and is a powerful technique for pattern classification. It is a process to group, based on some defined criteria, two or more terms together to form a large collection. In the context of image segmentation, it is often considered as the multi-dimensional extension of the thresholding technique.

Edge Detection: Edge detection is the most common approach for detecting discontinuities in images, and is the fundamental step in edge-based parallel process for segmentation. An edge is a local concept. To form a complete boundary of an object, edge detection should be followed by edge linking or connection.

Gradient Operator: Gradient operator is the first type of operators used for edge detection. The gradient of an image is a vector consisting of the first-order derivatives (including the magnitude and direction) of an image.

Graph Search: Graph search is a particular type of segmentation techniques which combing edge detection and linking together. It represents edge segments in the form of a graph and searching the graph for low-cost paths that correspond to significant edges or boundaries of objects.

Image Engineering: An integrated discipline/subject comprising the study of all the different branches of image and video techniques. It mainly consists of three levels: Image Processing, Image analysis, Image understanding.

Image Segmentation: A process consists of subdividing an image into its constituent parts and extracting these parts of interest (objects) from the image.

Region Growing: Region growing is a region-based sequential technique for image segmentation by assembling pixels into larger regions based on predefined seed pixels, growing criteria and stop conditions.

Thresholding: Thresholding techniques are the most popularly used segmentation techniques. A set of suitable thresholds need to be first determined, and then the image can be segmented by comparing the pixel properties with these thresholds.

Watersheds: Watershed technique is inspired from the topographic interpretation of images Segmentation by watersheds embodies many concepts of edge detection, thresholding and region processing techniques, and often produces stable and continuous results.