Contribution to modification of Graph cut method and its implementation in the image segmentation

I. Zolotová, P. Karch

Abstract—This article presents the implementation of methods to improve Graph cut segmentation. An initialization contour in the form of approximate tracing of the object for segmentation is used for initialization. The proposed modifications are designed to change the value setting of edges in the graph, implementation of iterative method and optimization of efficiency and accuracy. The modifications bring less dependence on user-set constants of Graph cut segmentation and thereby simplify user interaction. The experimental verification of the proposed modifications is tested for the efficiency, accuracy and repeatability of these modifications.

Keywords—evaluation, Graph cut, initialization, iterations, segmentation.

I. INTRODUCTION

$\mathbf{S}$EGMENTATION is generally defined as the process of separating an image into two or more segments: objects and background. The Graph cut segmentation may be initialized by automatic [6] or interactive [1] identification of the terminals of the objects and background. The Graph cut segmentation technique [2] is mainly initiated interactively by the user. The user interactively determines hard constraints in the form of terminals called S (source) and T (sink), by specifying certain pixels called seeds that necessarily have to be part of the object and certain pixels that necessarily have to be part of the background. The cost function of the segmentation is defined by terms of boundary and region properties of the segments. These properties can be viewed as soft constraints for segmentation.

The Graph cut segmentation belongs to advanced segmentation techniques based on determination of the cut of the graph. This cut of the graph is located in places with maximum flow in the graph. Algorithms such as Ford-Fulkerson algorithm or algorithm described in [3] are used to determine the maximum flow in the graph. The second algorithm is most frequently used in the Graph cut segmentation to determine the maximum flow and minimum cut of the graph.

Evaluations of the resulting segmentation are performed by determining the repeatability [4], [5], accuracy [10] and efficiency [4], [19] of the segmentation.

The repeatability of the method determines the extent to which the user can affect the resulting segmentation by various locations of initialization seeds, in our case different initialization contour. The repeatability is determined [5] as

$$PR_{e_1 e_2} = \left(1 - \frac{\left| C_{e_1} \oplus C_{e_2} \right|}{\left| C_{e_1} \right| + \left| C_{e_2} \right|} \right) * 100 \ [\%] \tag{1}$$

where $\left| C_{e_1} \right|$ and $\left| C_{e_2} \right|$ are the number of pixels of the final segmentations after two user initializations and $\left| C_{e_1} \oplus C_{e_2} \right|$ determines the number of pixels where both experiments do not match. Repeatability is better if it approximates to value 100%.

The accuracy of the segmentation is defined as the deviation of the resulting segmentation achieved by testing segmentation algorithm from the desired segmentation determined manually by experts. The accuracy is determined [10] as

$$A_e = \left(\frac{2 * TP}{2 * TP + FP + FN} \right) * 100 \ [\%] \tag{2}$$

where TP is the number of pixels correctly identified as "object", FP is the number of pixels incorrectly identified as "object" and FN is the number of pixels not identified as "object". The accuracy (2) calculated with more identifications of the pixels is not only more accurate but may be compared to a simplified implementation of the higher values of deviation. The smaller the deviation, the better the accuracy.

The efficiency is determined by the total time T_c required to perform an overall segmentation by the proposed algorithm

$$E_M^C = \frac{1}{T_c} \ [\text{fps (frame per second)}] \tag{3}$$

which determines the overall speed of the implementation of segmentation in the number of frames per second. The smaller the time, the better the efficiency.

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The initialization details used for the Graph cut segmentation method are shown in Section II A. This method of initialization is used for optimization of the repeatability. The details of the Graph cut segmentation method are shown in Section II B that doesn't need filtering [11]. Section II C provides details about iterative method for heterogeneous images. Section II B and Section II C bring optimization of accuracy. The details about optimization of efficiency are shown in Section II D. Section III gives the description of experimental verification of the functionality and evaluation of the proposed modification of the Graph cut segmentation method in Matlab software on the set of the selected input images.

II. MODIFICATIONS OF GRAPH CUT SEGMENTATION

A. Initialization

In our implementation of improvements to Graph cut segmentation, initialization by determining the contour [7] of the object specified for the segmentation is used. The method of implementation allows to reach a higher repeatability [4], [5] of the segmentation in repeated initializations. The initialization method based on the initialization contour automatically determines the position of seeds that identify the object and the position of seeds that identify the background and is used to initialize Graph cut segmentations. This way, it is achieved that locations of the "object" and "background" seeds are set uniformly and in sufficient number to achieve higher repeatability values.

B. Graph cut segmentation

Graph cut segmentation method [1], [2] belongs to the interactive segmentation methods, which divides an image into two segments "object" and "background". The method belongs to the graph algorithms, where the main idea is to create a valued, undirected graph $G = (V, E)$ from the input image I. This graph consists of a set of vertices V

$$V = P \cup \{ S, T \} \tag{4}$$

where P represents a set of pixels in the image I and terminals S a T are determined by automatic identification of seeds from initialization contour. A set of edges E

$$E = N \bigcup_{p \in P} \{\{p, S\}, \{p, T\}\} \tag{5}$$

in the graph are represented by the value of the links between the neighboring pixels $\{ p, q \} \in N$ whose edges are called *n-links* and the value of the links between terminals and pixels itself $\{p, S\}$, $\{p, T\}$ called *t-links*. How to evaluate these edges against [1], [2] is determined by the values in Table 1.

The cut C is a subset of edges $C \subset E$ which, when removed from G, disjoints V into two subsets S and $T = V - S$ so that $s \in S$ and $t \in T$. Then the cost of the cut [17], [18] is defined as a sum of the cost of these edges

$$|C| = \sum_{e \in C} w_e \tag{6}$$

The minimum cut is the cut with the smallest cost.

TABLE 1
VALUES SETTING OF EDGES IN THE GRAPH

Edge	Value	for
$\{p, q\}$	$B_{\{p,q\}}$	$\{p, q\} \in N$
$\{p, S\}$	∞	$p \in O$
	0	$p \in B$
	$\lambda \cdot R_p("bkg") + DT_p$	$p \in P, p \notin O \cup B, p \in IC_{inside}$
	$\lambda \cdot R_p("bkg") - DT_p$	$p \in P, p \notin O \cup B, p \in IC_{outside}$
$\{p, T\}$	0	$p \in O$
	∞	$p \in B$
	$\lambda \cdot R_p("obj") - DT_p$	$p \in P, p \notin O \cup B, p \in IC_{inside}$
	$\lambda \cdot R_p("obj") + DT_p$	$p \in P, p \notin O \cup B, p \in IC_{outside}$

Constant λ describes the importance of the regional properties versus the boundary properties. The distance transformation DT_p determines the distance of each pixel in the image from the initialization contour. The description $p \in IC_{inside}$ in this case means that the pixel is inside the area bounded by the initialization curve and $p \in IC_{outside}$ means that the pixel is located outside the area bounded by the initialization curve. For simplicity of this designation, a mask is used where each pixel inside the contour is identified as "1" and all pixels outside the contour are identified as "0".

Values of *n-links* are determined on the basis of [2] as

$$B_{\{ p,q \}} = exp\left(-\frac{\left(I_p - I_q^M\right)^2}{2\sigma^2} \right) \cdot \frac{1}{dist(p,q)} \tag{7}$$

where I_q^M is the median value of pixel q that is in the neighborhood of pixel p on the left, right, top or bottom from it. The value of $dist(p,q)$ is the Euclidean distance [12] of neighboring pixels and σ is a user defined constant that ensures the value of $B_{\{ p,q \}}$ will grow by shrinking the intensity values of the neighboring pixels and approximate to zero if the intensity values of the neighboring pixels is close.

C. Iterative method for heterogeneous images

In the case of heterogeneous objects and background there are individual set of pixels which determine the terminals of the objects and the background is also heterogeneous. Therefore, the procedure for determining $R_p(\cdot)$ and the segmentations is modified by the modified iterative method [11] for creating and processing the graph:

1. For each terminal based on the histograms the values of the set of terminal seeds, the number of values $s_i \in S$ and $t_i \in T$ is determined that we want to achieve from these histograms [13], [14].

2. Histograms of the individual terminals are evenly distributed to the specified number of sections and based

on that [8] the peaks of the waveform of the evenly divided histograms are determined. Under these peaks the values of terminals $s_i \in S$ and $t_i \in T$ for the calculation (8) are determined.

3. For each combination of values of S and T terminals provided in the previous step there is created a graph G_i according to Table 1, where for the values $R_p(\cdot)$ we have:

$$R_p("bkg") = t_i - I_p$$
$$R_p("obj") = s_i - I_p \qquad (8)$$

4. For the following graphs G_i, maximum flows fG_i of these graphs and their segmentations as $labelingG_i$ are determined.

5. Minimum and median values are determined of all the maximum flow values fG_i.

6. Determine the minimum and median value of fG_i. Subsequently, segmentations $labelingG_i$ are determined that satisfy $fG_i == min(fG_i)$ and $fG_i > median(fG_i)$ conditions. Segmentation satisfying the first condition ensures the basic segmentation and segmentations satisfying the second condition specify it with the pixels p labeled as "object" and belonging to IC_{inside}.

D. Optimization method

The speed of the Graph cut segmentation method depends on the size of the segmented image. It is convenient to not solve global segmentation of the whole image but only locally. Therefore, for optimization of the segmentation process there was created a method for optimizing implementation whose principle is as follows:

1. To initialize with the modified initialization method, the globally defined space is used.

2. This area is subsequently transferred to the local concluded space for segmentation, which is bounded by the automatic determination of pixels belonging to the outside terminal "background". Instead of the graph $G = (V, E)$ with the size of the input image $M \times N$ the graph $G' = (V', E')$ of size $M' \times N'$ is used, which are determined by (9) where dM is the neighborhood used for determining the median.

$$M' = \max_{t_i \in T: i=1,...n-(step+1)} m_{t_i} - \min_{t_i \in T: i=1,...n-(step+1)} m_{t_i} + 2*dM$$
$$N' = \max_{t_i \in T: i=1,...n-(step+1)} n_{t_i} - \min_{t_i \in T: i=1,...n-(step+1)} n_{t_i} + 2*dM \qquad (9)$$

3. In this space then all the modified method such as a modified method of determining values in the graph or a modified iterative method are performed.

4. The resulting segmentation of this space is finally transferred to the original global space.

III. EXPERIMENTS

These experiments show experimental application and

verification of the functionality of the proposed modification of the Graph cut segmentation method in Matlab software on the sets of input images.

Modified method of initializing
- Create the initialization contour in global space
- Using the *method of automatic identification* of seeds of "object" and "background"

Determination of processing method
- Global processing method (the entire image processing)
- Local processing method (local processing of the image)
  - Perform the transfer using the *method for implementing optimization*

Create a graphs
- Create a graph $G_i=(V,E)$ from the image intended for the segmentation
- Evaluation of edges of the n-links and t-links in the graphs G_i using the *modified method for determining values in the graph* with the decision to use or unuse the *modified iterative method*

Graph cut segmentation
- Determine the maximum flow of the graphs and determine the minimum cut of this graphs
- Determine the final segmentation based on the established conditions.

Backward determination of processing method
- Global processing method (the entire image processing)
- Local processing method (local processing of the image)
  - Perform the reverse transfer using the *method for implementing optimization*
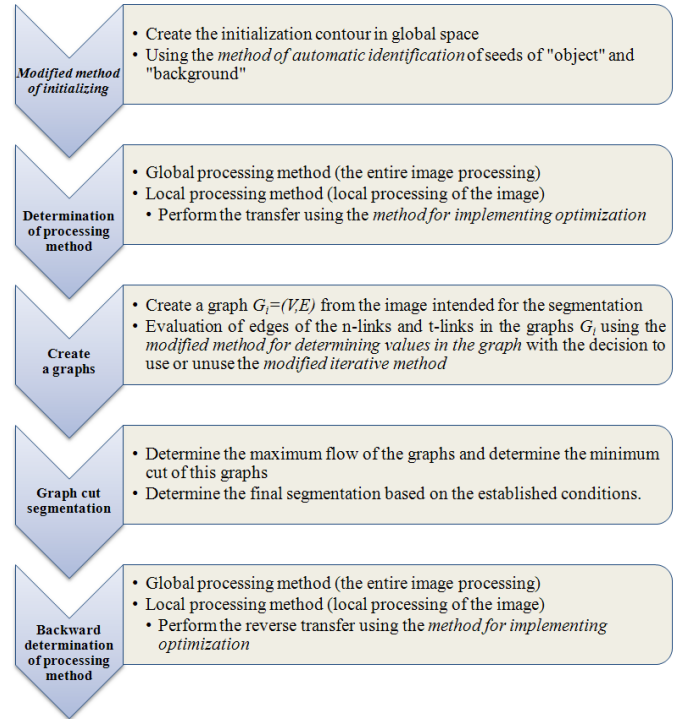
Fig. 1 Implementation of the proposed modifications in the Graph cut segmentation

The proposed segmentation algorithm Fig. 1 is based on the modified method of initialization [7], a modified method of determining values in the graph shown in Table 1, a modified iterative method and consists in this case of the following steps:

1. For the input image Fig. 2, the initialization contour is created by approximate tracing of the object specified for segmentation Fig. 3 (left).

2. Automatic identification method is used to determine the location of the seeds of "object" and "background" terminals Fig. 3 (right).

3. Determine the number of values $s_i \in S$ and $t_i \in T$ that we want to achieve from histograms of terminal seeds Fig. 6 and Fig. 7.

4. Create graphs G_i generated by a modified iterative method and determine the values of their edges using the modified method of determining the values in the graph according to Table 1, where the values of *n-links* are sufficient to establish once and apply to all graphs G_i. Values of *t-links* are established for individual graphs as a combination of terminal values of the object and background in step 3.

5. Iterative determination of Graph cut segmentation determining $labelingG_i$ for individual charts G_i [8] and determination of their flow fG_i.

6. Determine the minimum and median value of fG_i.

7. Subsequently, segmentations $labelingG_i$ are selected that satisfy $fG_i == min(fG_i)$ and $fG_i > median(fG_i)$ conditions. The segmentation satisfying the first condition ensures the basic segmentation and segmentations satisfying the second condition specify it with the pixels p labeled as "object" and belonging to IC_{inside}.
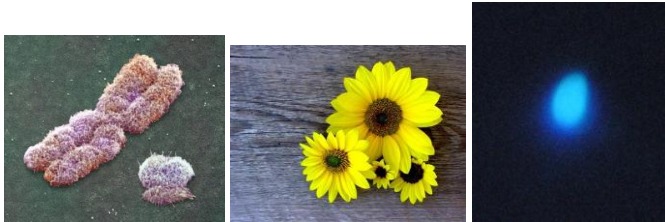

Fig. 2 The input images selected for the Graph cut segmentation Left) The first test image, Center) The second test image, Right) The third test image
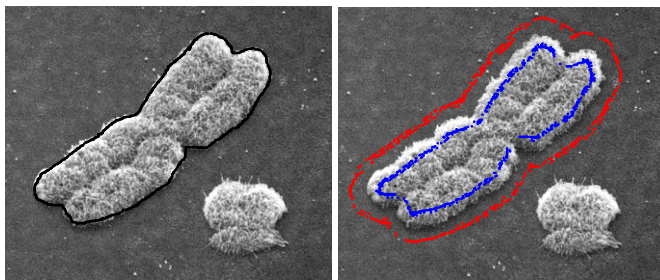
Fig. 3 Initialization contour (left) and automatic determination of the seeds of "object" and "background" terminals (right) for the first test image

Fig. 4 Initialization contour (left) and automatic determination of the seeds of "object" and "background" terminals (right) for the second test image
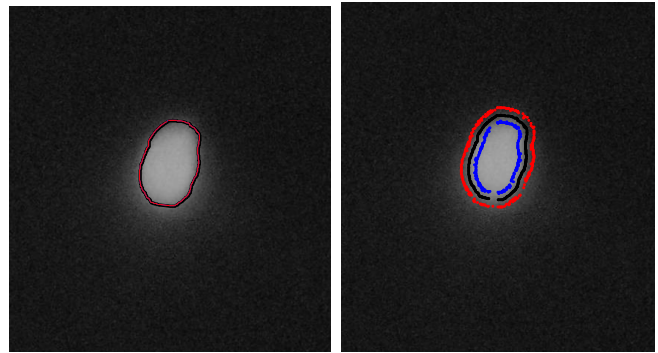
Fig. 5 Initialization contour (left) and automatic determination of the seeds of "object" and "background" terminals (right) for the third test image
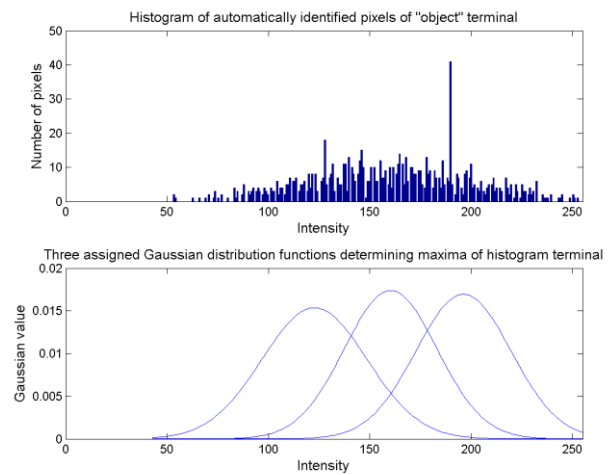
Fig. 6 Determination of the three brightness values terminals based on the histogram analysis for the "object" of the first test image

Based on the course of distribution functions Fig. 6 (down) it can be determined that all of the three peaks of the terminal T are required to achieve better accuracy.
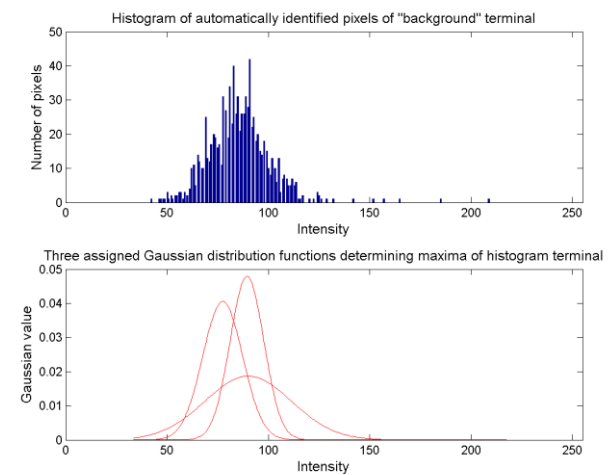

Fig. 7 Determination of the three brightness values terminals based on the histogram analysis for the "background" of the first test image

Based on the course of distribution functions Fig. 7 (down) it can be determined that instead of the three peaks of the terminal T only two peaks are required and thereby increase the efficiency while similar accuracy is achieved.
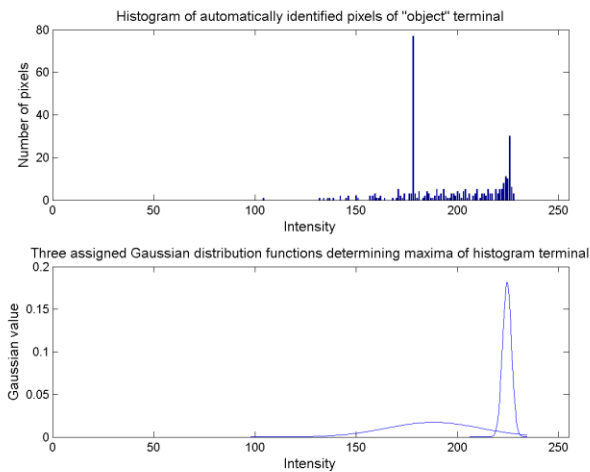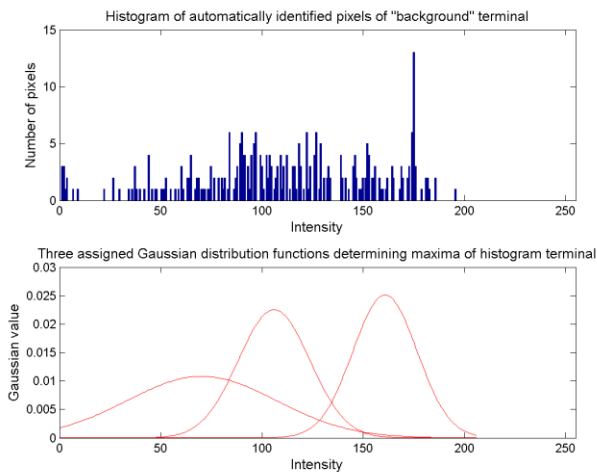

Fig. 8 Determination of the three brightness values terminals based on the histogram analysis for the "object" of the second test image

Based on the course of distribution functions Fig. 8 (down) it can be determined that instead of the three peaks of the terminal S only two peaks are required and thereby increase the efficiency while similar accuracy is achieved.

Fig. 9 Determination of the three brightness values terminals based on the histogram analysis for the "background" of the second test image
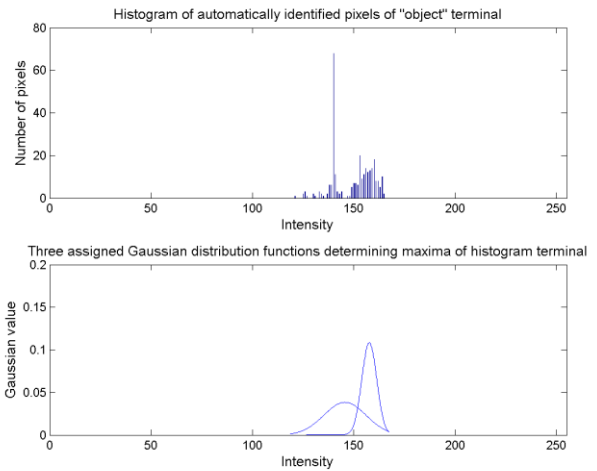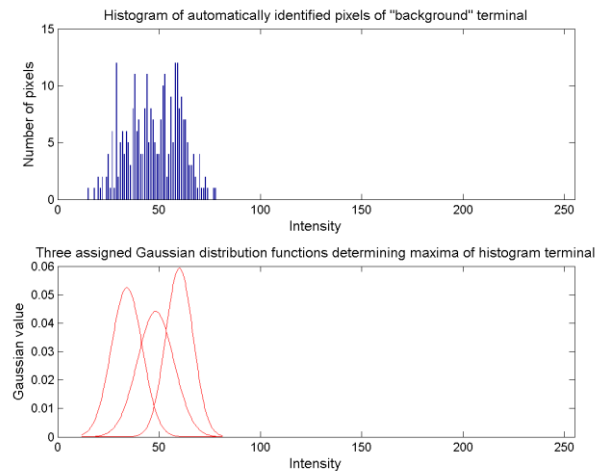

Fig. 10 Determination of the three brightness values terminals based on the histogram analysis for the "object" of the third test image

Based on the course of distribution functions Fig. 10 (down) it can be determined that instead of the three peaks of the terminal S only two peaks are required and thereby increase the efficiency while similar accuracy is achieved.

Fig. 11 Determination of the three brightness values terminals based on the histogram analysis for the "background" of the third test image

Based on the course of distribution functions Fig. 11 (down) it can be determined that all of the three peaks of the terminal T are required to achieve better accuracy.
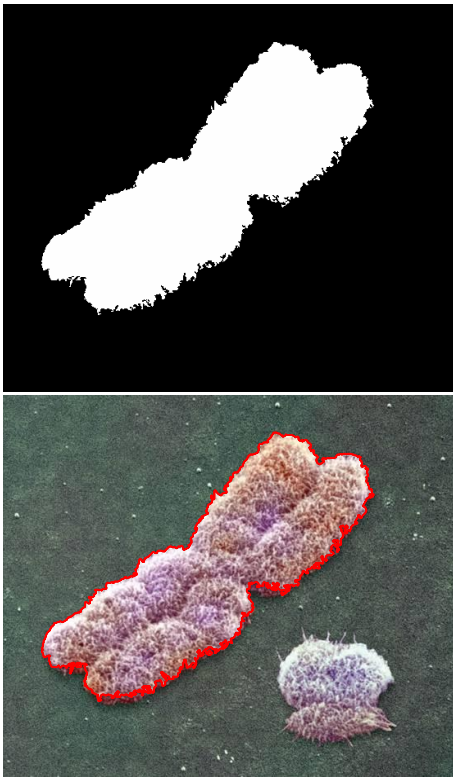
Fig. 12 The result of object segmentation and highlight (up) of the segmented object in the input image (down) for the first test image
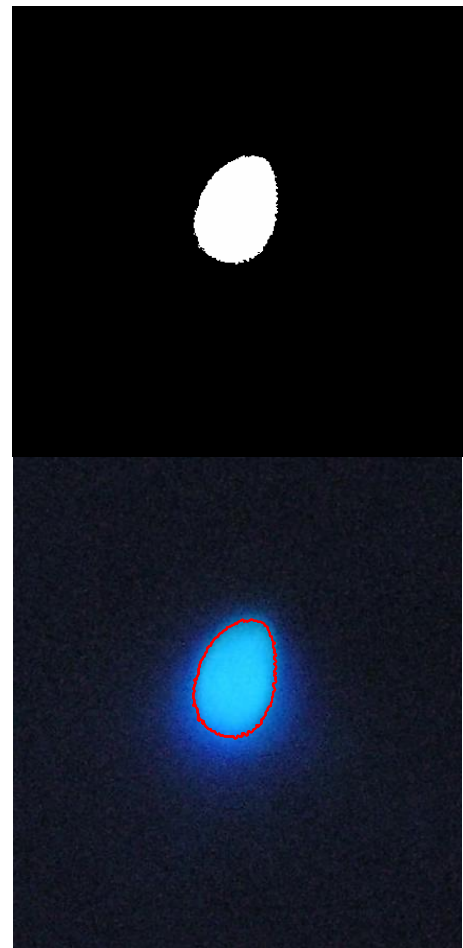

Fig. 13 The result of object segmentation and highlight (up) of the segmented object in the input image (down) for the first test image

Fig. 14 The result of object segmentation (up) and highlight of the segmented object in the input image (down) for the third test image

The accuracy of the segmentation in Fig. 12 (up) was determined for the manually segmented object and determines deviation from the best achievable segmentation in Fig. 2 (left) based on the segmented image according to a modified iterative algorithm and differs from the manual segmentation by only 95.18 %. Depending on the specified number of values selected for the terminals the following accuracy is achieved as shown in Table 2.

The accuracy of the segmentation in Fig. 13 (up) was determined for the manually segmented object and determines deviation from the best achievable segmentation in Fig. 2 (center) based on the segmented image according to a modified iterative algorithm and differs from the manual segmentation by only 97.35 %.

The accuracy of the segmentation in Fig. 14 (up) was determined for the manually segmented object and determines deviation from the best achievable segmentation in Fig. 2 (right) based on the segmented image according to a modified iterative algorithm and differs from the manual segmentation by only 94.99 %.

All the results obtained are also dependent on the accuracy of manual segmentation for which the accuracy of

segmentation is determined.

TABLE 2
ACCURACY OF PROPOSED ITERATIVE METHOD FOR THE FIRST TEST
IMAGE

Number of values of terminal S	Number of values of terminal T	Accuracy
1	1	91.12 %
2	2	93.31 %
3	2	94.33 %
3	3	95.18 %
4	3	95.87 %
4	4	96.27 %

The advantage of this modification is that increasing the number of terminal values obtained from the histogram results in improvement of the accuracy of the resulting segmentation of the input image. From the iterative approach, it is possible to clearly establish the disadvantage of the iterative approach and its impact on the effectiveness of this modification.

The overall efficiency of segmentation is decreased to 0.0280 fps by this iterative way of segmentation. Depending on the specified number of values selected for the terminals, the overall efficiency of segmentation is in the range of Table 3.

TABLE 3
EFFICIENCY OF PROPOSED ITERATIVE METHOD FOR THE FIRST TEST
IMAGE

Number of values of terminal S	Number of values of terminal T	Efficiency
1	1	0.1087 fps
2	2	0.0460 fps
3	2	0.0400 fps
3	3	0.0280 fps
4	3	0.0220 fps
4	4	0.0168 fps

Based on the summary of Table 2 and Table 3 it can be stated that setting the suitable number of values of individual terminals the improvement with the least possible reduction in efficiency can be achieved. The advantage of this modification is that every increase in the values obtained from their terminals histogram is the improvement in the accuracy of the resulting segmentation of the input image. From the iterative approach of this method it is possible to clearly specify the disadvantage of this approach and its impact on the effectiveness of this modification.

Repeatability of the iterative method reaches 99% compliance of two segmentations at repeated initialization.

The difference in the results between the non-iterative (without Section II C) and iterative (with Section II C) approach is shown in Table 4.

TABLE 4
THE COMPARISON OF RESULTS USING THE NON-ITERATIVE AND
ITERATIVE APPROACH

Method	Initialization	Accuracy	Efficiency	Repeatability
Non-iterative approach	Initialization contour	91.20 %	0.1087 fps	99 %
Iterative approach	Initialization contour	95.18 %	0.0280 fps	99 %

As methods for comparing the results obtained using the proposed modification with other methods of segmentation Grow cut method [20] and Grab Cut method [21] were chosen. The results achieved by the proposed modifications, the Grow Cut method and Grab Cut method in Fig. 2 (left) are in Table 5.

TABLE 5
THE COMPARISON OF RESULTS USING THE PROPOSED MODIFICATIONS AND
GROW CUT METHODS

Method	Initialization	Accuracy	Efficiency	Repeatability
Proposed modifications	Initialization contour	95.18 %	0.028 fps	99 %
Grow Cut	Initialization seeds	92.60 %	0.118 fps	97.26 %
Grab Cut	ROI	91.50 %	0.060 fps	96.47 %

Matlab wrapper library [9], [3] that is used for the Graph cut is compiled and implemented in Matlab R2007a. All the experimental results are given with CPU Core2Duo 2.13GHz, 3GB RAM and 256MB VGA on Windows XP Pro.

IV. CONCLUSION

The proposed iterative method is more accurate than the compared not-iterative method by about 4%. This can be determined on the basis of the results in Table 4. It is possible to conclude that if objects are more heterogeneous than homogenous, it is preferable to use the modified iterative method. The proposed modifications achieved better accuracy and repeatability of the resulting segmentation in comparison with the methods such as "Grow cut" or "Grab cut" methods. The proposed modifications achieve slightly worse results of the effectiveness compared to these methods.

Compared with traditional manual initialization by identification object and background terminals seeds, with the initialization [7] it is possible to achieve a much better repeatability amounting up to 20% depending on the user initialization.

Effectiveness of the proposed modifications can also improve in Matlab with their implementation on the GPU (Graphics Processing Unit) [15]. Further work will also be focused onto experiments with implementation into one of object-oriented languages as C++.

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