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Enhancement of document readability

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Enhancement of document readability

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Introduction and background

This report intends to introduce the reader to TZI and the preliminary work done in Bremen in April 2006, regarding the enhancement of the readability of faded, unclear and damaged complex documents.

TZI (<http://www.tzi.de>), the German acronym for the Center for Computing Technologies, is a research and development center associated with the University of Bremen, funded partially by the university but mainly by external funds. It involves more than 140 researchers, also on the senior professorial level. A large part of the work of TZI is done as part of doctoral dissertations research. For details, see the cited web site, available both in German and in English.

Dr. Gideon Frieder has long standing ties with the TZI. The work reported here is a joint effort to solve an actual problem based on results

*Updated August 20, 2007

achieved in the TZI. The second author is a doctoral student in the TZI department of Image Processing in the University of Bremen. The third author was a member of the TZI department of Image Processing until April 2006. The TZI has done a considerable amount of work in Image Processing since its start in 1995.

1 Problem definition, preliminary tools and image representations

Given an image of a faded, washed out, damaged, crumpled or otherwise difficult to read document, with mixed handwriting, typed or printed material, with possible pictures, tables or diagrams, enhance the readability and comprehensibility of the document. Documents may have multiple languages in a single page.

The basic idea is to create a tool that utilizes the image processing basic methods available in TZI, through the use of the OpenCV library¹ and other programs that implement algorithms and interfaces. OpenCV is the name of the Intel Open Source Computer Vision Library [Int01]. Images can be viewed through the specifically developed tool, which provides a range of capabilities as described below. They also can be viewed through utilities available in the Windows environment or other such programs.

Each document is considered to be an image composed from a two dimensional matrix of pixels, each described by three bytes, each byte representing one of the RGB (Red Green Blue) components of the pixels. The image is available as stream of input from multiple possible channels. These are the whole color image, each of the RGB inputs, a gray tone image produced by a generalized linear combination of the RGB channels (see below), or a linear combination of all of these. Details and formulas are provided later in this report.

The presumption is that any document can be (manually if necessary) segmented into textual and non textual parts, so as to isolate any pictures and diagrams. Tables are considered as text. As we noted before, our goal is to process the isolated text, which can be an arbitrary mix of typed, printed or handwritten materials, so that the resulting image of the text will be easily

¹see <http://www.sourceforge.net/projects/opencvlibrary>

readable.

At this stage, we do not worry about the segmentation, as there are no algorithmic or technical issues in implementing it. We have a large corpus of sample documents that we can use for our experimentation without any need for segmentation.

2 Gray level generalized transformation and image representation

The original RGB color image, representing each pixel by three bytes, can be transformed into a byte per pixel gray tone image (or gray level image - a frequently used term), where each pixel represents a light intensity denoted by I , computed by $I = aR + bG + cB$ where a, b, c are positive numbers so that $a + b + c = 1$.

The customary transformations are $a = b = c = 1/3$, which is just the arithmetic mean, or the classical gray scale transformation where $a = 0.299$, $b = 0.587$, and $c = 0.114$. In the literature, there is also a transformation via a geometric mean, but we did not find a need to consider it in our context. In our tool, at this time, we used the gray level transform with the classical parameters.

Through the processing steps, we produce images that are conceptually binary. These are referred to as masks, and are traditionally viewed as being represented as zero or one values. In our approach, however, we shall use smoothing methods that work on gray level values. Therefore, in our system, binary images or masks are represented as gray level images with values of either zero or 255.

3 Basic Approach

The underlying idea of the approach is to produce a binary mask that is used to emphasize regions (the characters) in the input image. This binary mask can be obtained through a foreground – background separation [SP00, TT95] by various algorithms whose details are described below. As stated before, the binary mask thus produced is then converted to a gray level image. This image is then convolved with a Gaussian kernel [Jae97] to produce an overlay

image. The overlay is superimposed on the background image, selected by the user, to raise the contrast of the characters and make the document more readable. The Gaussian smoothing of the gray level representation of the binary image is used to obtain a more smooth and natural-looking result. Figure 1 illustrates the overall process flow.

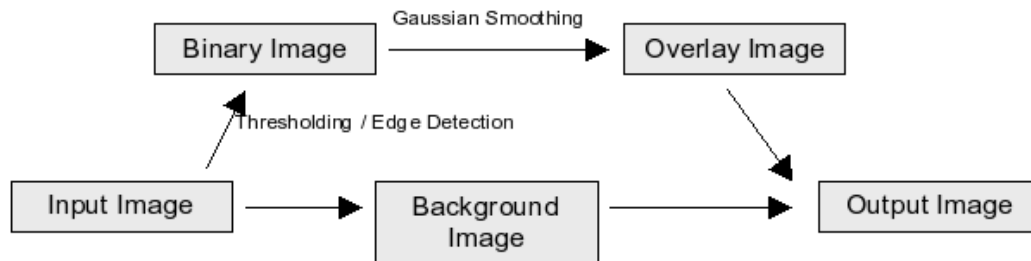


Figure 1: Overall process flow.

4 The ENH tool – general description

The tool, denoted currently as ENH, is driven by a GUI (see figure 2) which provides for multiple methods for the major steps illustrated above, and the selection of parameters for each of these and other, more minor steps. The GUI presents five consecutive steps; these are the selection of the input component, the method to create the binary image, isolated regions filter, background image selection and overlay image creation. Each of these has parameters whose input template is provided in the interface. It is important to read carefully the full description of the parameters that are described below, as the actual values used in the programs are sometimes a function of the input (see, for example, *Window Size*), or the input is described as percentage, so that 80 really has the value 0.8 (see, for example, *Factor*). Once selected, sets of input parameters can be stored in a file, and obviously, once a file of parameters exists, it can be loaded into the tool.

The options and their parameters are as follows: (*bold letters reflect the caption in the GUI uppermost level*)

1. Selection of the **Input Components**.

- Combination (the I transformation with the classic parameters)
- Red Component (as a gray tone image)
- Green Component (as a gray tone image)
- Blue Component (as a gray tone image)

2. Creation of the **Binary Image**

- Weighted Mean (locally adaptive thresholding)
 - Window Size
 - Threshold
- Min/Max (locally adaptive thresholding)
 - Factor
 - Min Delta
 - Window Size
- Sobel (edge detection)
 - Threshold
 - Aperture Size
- Canny (edge detection)
 - Threshold 1
 - Threshold 2
 - Aperture size

3. **Filter dust regions**

- Region Size (in pixels)

4. Selection of the **Background Image**

- Color Image (the original)
- Combination (the I transformation with the classic parameters)
- Red Component (as a gray tone image)
- Green Component (as a gray tone image)
- Blue Component (as a gray tone image)

5. Overlay image creation

- Gaussian Mask Size
- Input:
 - Sampled Color
 - Gray (classical transformation)
- Overlay Amount

Some of these steps and their parameters are self explanatory, but for completeness we shall describe all of them.

The selection of the input provides flexibility to deal with all the components or part of them. We intend, in the future, to provide the general transformation as provided. At this stage, we did not find any real need for it. Inasmuch as its addition is trivial, we delay it to a time of need. In almost all of our experimentation, we used the gray level transform.

The main power of the tool is in the selection of the the method for the creation of the binary image. Here we provide four methods, which are the locally adaptive thresholding method (Weighted Mean), a variant of the adaptive thresholding method (Min/Max), the Sobel [DH73] based edge detection method and the Canny [Can86] edge detection based method.

4.1 Locally adaptive thresholding and variants thereof

The first variant of binary image creation, designated as "Weighted Mean" in our GUI, is simply the built-in adaptive thresholding from the OpenCV library (implemented in the function `cvAdaptiveThreshold` for those familiar with the OpenCV API). This calculates the weighted mean in a rectangular neighbourhood of a pixel and takes this value, subtracted by a selected value, as the local threshold. The weighting is given by a Gaussian mask of the size of the neighbourhood, which is given by the parameter *Window Size*, where the actual size of the neighbourhood, in pixels, is $neighborhoodSize = (2windowSize + 1) \times (2windowSize + 1)$. The constant subtracted from the weighted mean to calculate the local threshold is given by the parameter *Threshold*.

One problem with the approach described above is that it depends on the characteristics of the neighbourhood, e.g. near the borders of a text block

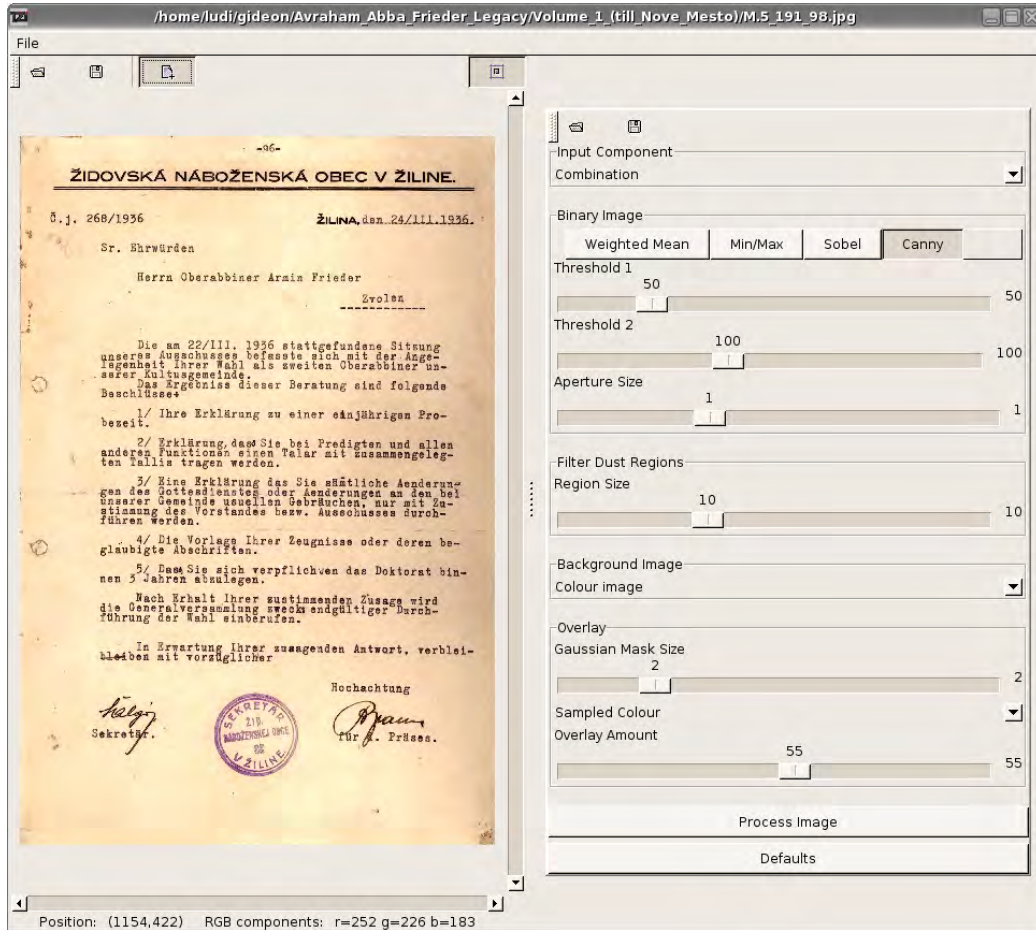


Figure 2: ENH user interface.

where most of the area in the neighbourhood is pure background, the threshold tends to be higher than in the middle of a text block. As we know that we always have to distinguish two classes of pixels (namely dark characters and light pixels from the background) and pixels from each class can be assumed to have a locally similar intensity, we implemented a variant of the approach described above that depends on the minimum and maximum intensity inside the neighbourhood of a pixel. This method is named "Min/Max" in the GUI.

Any method that depends on minimum and maximum values is sensitive to outliers, so in order to mitigate their effect, we start with an initial smoothing by applying a 3×3 median operator. The local threshold is again calculated from the local neighbourhood. The size of this neighbourhood is given by the *Window Size* parameter and the actual size is calculated as above.

Let g_{min} and g_{max} be the minimum and maximum gray value of the smoothed image in this neighbourhood and $delta = g_{max} - g_{min}$ the difference between the minimum and maximum values. The local threshold is calculated by $t = g_{min} + delta \cdot f$ for a given coefficient f (the parameter *Factor*). This parameter is expressed in the interface in percent value.

The main idea in this approach is not to subtract a constant from the mean or value between the maximum and minimum gray value, but to be adaptive to the local contrast. This is represented by $delta$, and thus is more sensitive in image regions with low local contrast. Furthermore we only apply this threshold if $delta$, and thus the local contrast, is above a threshold given by the parameter *Min Delta*.

4.2 Edge detectors

Another way to produce the binary mask is the application of edge detectors. We integrated two approaches for edge detection. The first one is done by the convolution of the input image with a 3×3 Sobel [DH73] kernel in x - and y -directions to gain an approximation of the gradient of the image function in horizontal and vertical direction (G_x and G_y), and the computation of the direction-independent gradient magnitude $G = \sqrt{G_x^2 + G_y^2}$ (note that in the actual implementation G_x and G_y are represented as 8-bit gray level images, so we take the absolute result of the application of the Sobel kernels and divide it by 4 to scale it to the interval [0..255]). Then a threshold (*Threshold*

in the interface) is applied to the gradient magnitude to produce the binary mask. Note remark below about the values of the parameter *Aperture Size*.

The other edge detector we integrated is the OpenCV implementation of the Canny edge detection algorithm [Can86]. The Canny algorithm also relies on the gradient of the image function, but further applies edge linking starting at strong edge segments with a gradient magnitude larger than a given threshold and tracking the edges as long as the image gradient is above a certain threshold. The two thresholds are given as *Threshold1* and *Threshold2* where the larger of these is used to find strong edge segments to start edge tracking and the smaller is applied while tracking an edge. The aperture size of the Sobel mask used for computation of the gradient of the image function is also adjustable and given by the parameter *Aperture Size*. Note, again, that this parameter is used to compute the actual neighbourhood size as described above.

A note about *Aperture Size*: The Sobel kernel is always of size 3. The "Sobel" and "Canny" algorithm use of larger aperture does not mean that the Sobel mask is larger than three. The customary interpretation of larger than 3 aperture size is that a Gaussian smoothing with mask size *ApertureSize* - 2 is performed prior to the application of the Sobel operator.

4.3 Filtering

Step three, the filter dust regions step, is intended to eliminate small clusters of pixels from the binary image. The various processes can produce noise in form of small clusters of pixels that are scattered throughout the binary image. This step will zero out (that is, set to maximum intensity) all clusters of pixels who have less than *Region Size* pixels.

Care has to be exercised when selecting this parameter, as many European languages contain diacritics whose size, in pixel count, is very small. These can be therefore accidentally lost by the filtering process. In the future, we shall implement an option to filter selected regions only, thus limiting the potentially harmful effect of this capability.

4.4 Overlay creation and its superimposition on the background image

Now that all the preliminary steps are done, one has to proceed to the final creation of the overlay and the selection of the background image on which the enhancing overlay will be superimposed.

The sources of the background image, as detailed in the description of the GUI, are obvious; they are chosen using the *Background Image* parameter. The background image can be either the color input image, one of the RGB components or a gray level, classical conversion.

As mentioned before, we may add in the future an additional source – the generalized gray level transformation. In that case, there will be a need for three parameters a , b and c . As with other parameters, upon loading ENH, these will assume default values (the classical values).

If the background image is a single-channel image (it is either one of the RGB components or the gray level conversion), the overlay and background images are combined by taking the minimum of the values in the overlay image multiplied by the *Overlay Amount* and the pixel value of the background image. Note that the *Overlay Amount* parameter is represented in the user interface by a percent value, so a chosen value of 80 means $OverlayAmount = 0.8$.

If the background image is a 3-channel color image (so it is the original input image) the user can select between the method described above, which is then applied to the three channels separately, and a second method that uses a shaded sampled color from the original image. The new intensity value for each of the three channels is then computed by $g_{new} = \max(0, g - amount * (255 - g_{overlay}))$ where g is the intensity value from the channel of the original image, $g_{overlay}$ is the value from the (single-channel) overlay image and $amount$ is the user-steered parameter *Overlay Amount* that controls the amount of overlay. Note here that we deal with dark character regions on a light background, so the smaller and thus darker the value in the overlay image is, the larger the value subtracted from the original value of the channel.

5 Using ENH

The ENH system is written in Java, using the Java Development kit (JDK 1.5.0_04), and C++. When invoked, it presents to the user, side by side, two panels. On the left is the image panel with its buttons. These include the obvious buttons to select the input document and another one to save the processed, enhanced image. It also includes a button for a rapid switch between the original and the enhanced image, and, on the right upper corner, a button to enable zooming and panning of the currently displayed image, be it the original or the enhanced one.

The bottom of the display panel includes a line of information, displaying coordinates of the current cursor position, as well as the RGB values of the pixel at that coordinate.

In the future, we shall add capabilities to extract and store rectangular regions, or to select regions for processing. A rudimentary capability to compose a document from image components may be provided as well.

On the right is the algorithm panel, that includes the selections described above, complete with the ability to create, store and retrieve parameter sets, and to switch between algorithms. If the use of the whole screen is desired, say after a processed image has to be viewed in great details, the right panel can be hidden (and revealed at wish) so that all the screen area is fully utilized.

ENH is currently mainly a development and experimentation tool. Once it is determined what algorithm and which parameters should be used for a group of documents, a batch facility may be provided, so that a production system to enhance a large number of documents could be put in place. We have such rudimentary facility at hand at this time, but elect to report on it in a future appendix, as it behoves us first to gain some experience with it, so that the final version will have the maximum usefulness.

The documents that were used as a preliminary test for our enhancement tool and the algorithms implemented therein, were taken out of the diary of Rabbi Dr. Avraham Abba (Armin) Frieder² [Fri], covering the period of 1933 to 1946. The diary is in the archives of the Yad Vashem museum in Jerusalem³, and the pages that we have were scanned by the museum

²Available online at: http://ir.iit.edu/collections/frieder.diaries_README.html

³<http://www.yadvashem.org/>

| Document | Description |
|-----------------|---|
| 193.67 | mixed typed/handwritten in German, with bad colorations of the paper |
| 193.95 | handwritten, Slovak language document with bad coloration, with highly varying intensity, in patches, of the background |
| 194_194 | a quite legible, typed document in German, with reasonably consistent intensity both of type and background. It is included to provide a test that our methods will not destroy already available readability |
| 194_221 | handwritten, vary faint document, with very little contrast between writing and background (it is in German) |
| 194_246 | typed in German, with reasonably constant background but with variations in the intensity of the type |
| 194_255 | typed in German and Slovak, with reasonably constant background but with very high variations in the intensity of the type |
| 194_259 | very faint, variable contrast, German handwritten document with reasonably constant background |
| 194_271 | mainly Slovak language typed document with very high variation, in different lines, of the visibility of the typed characters |

Table 1: Selected test documents from [Fri].

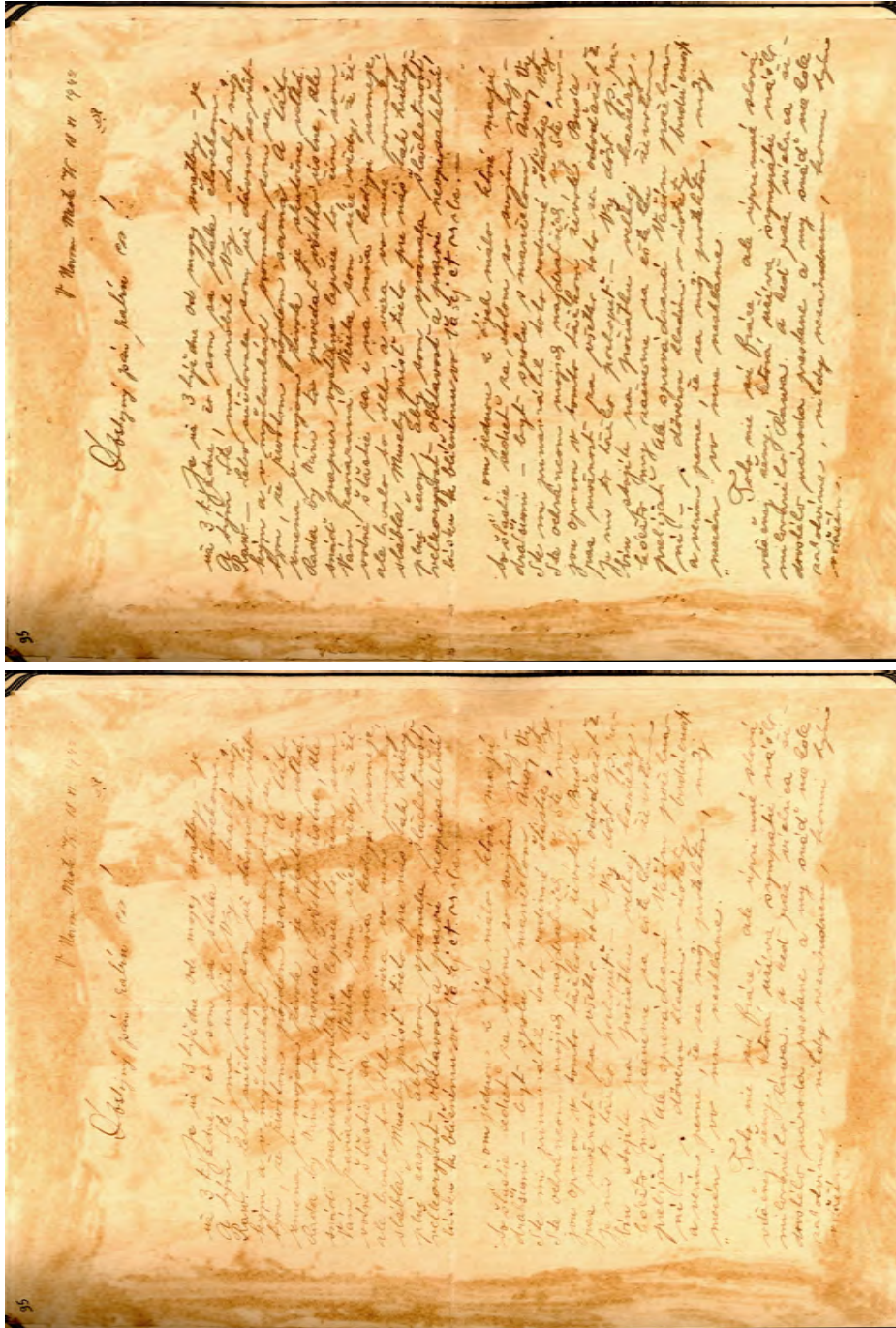
personnel. The pages of the diary are identified by the archival number M.5.19x_yyy, where x identifies one of the four volumes, and yyy is the page number. There are a total of approximately 880 pages in the diary

It is important to realize that archives are not the only source of damaged, illegible and faded documents, so that the tool we are developing has a wider use than enhancement of archives - in itself an important and worthwhile task. As a general remark, large part of the problems of readability and appearance of the currently used documents, such as bad coloration of the background, came from the age of the documents, the ravages of keeping them through WWII, and the effect of chemical preservation performed in the 70s of the last century. For other documents, the damage can be heat, fire, sunlight and so on, but we do consider the problems of our test set to be representative for other document types.

We used eight documents (pages, listed in table 1), selected because they present different problems of readability and clarity, they present handwritten and typed material and they are written in two different languages that posses different diacritic marks and in handwriting sometimes slightly different character forms.

6 Experimental results

The eight documents were processed using ENH, with different algorithms applied to different documents. In this report we provide illustrative sample results of three documents: The first one is one is 193_95, processed using the Canny edge detection based method (see figure 3), the second one is 194_246 processed using the locally adaptive thresholding method based on minimum and maximum (see figure 4) and the third one is 194_255, processed using locally adaptive thresholding based on the weighted mean (see figure 5). These are among the worst in our sample set. The images are presented without comment, as we are in the beginning, preparatory stage of this project, and no general analysis was done to date. Even so, the results speak for themselves, and show promising potential for a further development of a rather general tool for both research and actual archival enhancement for damaged and illegible documents.



(a)

(b)

Figure 3: (a) Original document (193_95). (b) Enhanced document.

246 -
- 13 -

hinterlistig, dass man schon ein sehr erprobter Diplomat sein muss und vor allem ein tiefer Menschenkenntnis diesen Wörtern zu durchschauen und in seine Karten Einblitz werfen zu können. Ich glaube, dass unsere Interventionen ihn total verkennt haben, denn sie glaubten einfach, als er den Burgfrieden auf 14 Tage versprochen hat, den Tag nach Jomkippur, am Donnerstag ging ich zu Gizi, die ich in Frühen aufgelöst gefunden habe, sie glaubte nämlich fest, dass man niemandem den Urlaub verweigern werde, insofern wurde er aber zusammen mit dr. Kováč zum Brunner geführt, (Ihnen sagen liess, dass sie zusammen mit ihm nach Sered fahren. Gizi war sehr unglücklich, hatte aber keine Ahnung was Brunner plant und beweinte nur die Leute, die nun in Sered sind. Während des ganzen Tages liefen verschiedene Informationen ein, die davon sprachen, dass sich in der Nacht eine " Obytača " vorbereitet, Ich war Neuling, wusste nicht was los ist und konnte auch die Situation nicht richtig einschätzen. Hatte Vertrauen zur Gizi, trotzdem ich auch der anderen Seite Glauben geschenkt habe. Als aber sowohl Gizi als auch Neumann die unterschiedene Erklärung abgegeben haben, dass vorläufig nichts zu befürchten ist, gingen wir alle beruhigt nachhause.

Unterwegs war ich aber entschlossen sowohl die Schwiegermutter als auch die Schwägerin wegzunehmen und nur ich bliebe zuhause, da ich mich der Arbeitsdisziplin der Gruppe zu unterwerfen irgenwie gebunden verpflichtet habe. Kaum legte ich mich aber nieder, da Klopfte man mir gegen 3/4 11 an der Türe. ~~Ich öffnete aber trotzdem nicht.~~ Plötzlich wurde aber die Tür gewaltsam aufgerissen und drang ein Gardist, Pagáč mit drei Soldaten ein, die das Gewehr auf mich gehalten haben. Ohne ein Wort zu sprechen schlug mich Pagáč mit seinem Kolben und die Soldaten drangen auf schnelles Anziehen und mit ihnen zu kommen. Und im Hofe, wach ein Bild, das ganze Haus von Soldaten besetzt. Ueberwiegend deutsche SS, SA, PS HU, aber auch sehr verlässliche HG und slowakische Soldaten umzingelten das ganze gewisse Getto in Preneburg besetzten alle Tore und Eingänge der Häuser, drangen in den Hofen und in allen Zimmern ein und schleppten die Juden in die Uff, also auf die Gasgasse und Edelgasse. Unterwegs gingen wir durch einen Kordon von SS PS Leuten, die alle das Gewehr gegen uns gehalten haben.

(a)

246 -
- 13 -

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(b)

Figure 4: (a) Original document (194_246). (b) Enhanced document.

45
-255-
- 22 -
Ich ging aus der Barake weg, taumelnd. Ein Ordner, Namens Béla Rosenzweig begleitet mich nachhause. Ich sprach nicht während des ganzen Weges. Kaum vor der Türe meines Zimmers angelangt sank ich zusammen und erhielt einen Weinkrampf, in welchem ich nur stotternd meinen Zimmerinsassen das Gehörte wiedergeben konnte.
Der Gedanke selbst war unfassbar. Die Nachricht niederschmetternd und ungläubbar. Ist es möglich eine Frau im jugendlichen Alter von 21 Jahren, eine Mutter zweier kleinen Kinder, so jäh zu verlieren. Ist es erfassbar, dass Knospen, die noch nicht einmal zur Rose heranreifen konnten, von roher Hand abgeknickt und weggerissen werden ? ? Eine furchtbare Nacht folgte dieser Nachricht, ich wollte mich selbst beruhigen, aber irgendwie fand ich keinen Trost.
Jedenfalls stimmte noch das Datum nicht und ich entschloss mich noch zu warten, bis ich nähere Daten bekommen werde.
Schon am nächsten Abend, am 14 kam wieder einer aus Bauska Bystrica und diesmal ein Prievizsner, Aladár Hagman, also ein Landsmann. Ich ging mit ihm mit dem Jungen Demidér Hiller, der die Nachricht mitkontrolliert, weil ich meinem Gebrüder selbst nicht getraut habe. Wagmann Aladár erkannte mich aber nicht und als ich ihn fragte " Do ste pöböl o pani rabínovej ? " antwortete er mir " Dejte mi pokoj. " Erst als ich mich zu erkennen gegeben habe, griff er sich bei den Haaren und sagte mir: " Ano, Vaša manželka spolu s Gáttukon boly 27 oktobra o 11 hodine predpoludním pri bombardovaní Starej Hory zabítá a Váš ohlapček bol na nohe ranený, avšak zachránený a do jednej, mne neznámej dediny zavedený. " " Aladár, fragte ich, je to pravda, o čer Schwie sedet ? " " Ano, pán Rabín " sagte er weinend, " sednite si schiwe. "
Gebrochen diesmal und tief erschüttert kehrte ich nachhause, liess mir ein Minjan zusammenbringen und vom Herrn Schönfeld, einem sehr ergebenen frommen Juden Kri' e schneiden und setzte mich Schiwe nieder.

(a)

45
-255-
- 22 -
Ich ging aus der Barake weg, taumelnd. Ein Ordner, Namens Béla Rosenzweig begleitet mich nachhause. Ich sprach nicht während des ganzen Weges. Kaum vor der Türe meines Zimmers angelangt sank ich zusammen und erhielt einen Weinkrampf, in welchem ich nur stotternd meinen Zimmerinsassen das Gehörte wiedergeben konnte.
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Jedenfalls stimmte noch das Datum nicht und ich entschloss mich noch zu warten, bis ich nähere Daten bekommen werde.
Schon am nächsten Abend, am 14 kam wieder einer aus Bauska Bystrica und diesmal ein Prievizsner, Aladár Hagman, also ein Landsmann. Ich ging mit ihm mit dem Jungen Demidér Hiller, der die Nachricht mitkontrolliert, weil ich meinem Gebrüder selbst nicht getraut habe. Wagmann Aladár erkannte mich aber nicht und als ich ihn fragte " Do ste pöböl o pani rabínovej ? " antwortete er mir " Dejte mi pokoj. " Erst als ich mich zu erkennen gegeben habe, griff er sich bei den Haaren und sagte mir: " Ano, Vaša manželka spolu s Gáttukon boly 27 oktobra o 11 hodine predpoludním pri bombardovaní Starej Hory zabítá a Váš ohlapček bol na nohe ranený, avšak zachránený a do jednej, mne neznámej dediny zavedený. " " Aladár, fragte ich, je to pravda, o čer Schwie sedet ? " " Ano, pán Rabín " sagte er weinend, " sednite si schiwe. "
Gebrochen diesmal und tief erschüttert kehrte ich nachhause, liess mir ein Minjan zusammenbringen und vom Herrn Schönfeld, einem sehr ergebenen frommen Juden Kri' e schneiden und setzte mich Schiwe nieder.

(b)

Figure 5: (a) Original document (194_255). (b) Enhanced document.

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