Tableau - Processing Teaching-board Images
Acquired with Portable Digital Cameras

Daniel Marques Oliveira and Rafael Dueire Lins

Departamento de Eletrônica e Sistemas – UFPE – Recife – PE – Brazil
danielmarquesoliveira@gmail.com, rdl@ufpe.br

Abstract

Portable digital cameras are of widespread use today due to good image quality, low cost and portability. Teaching-boards are the most universal classroom equipment throughout the world. This paper presents a software environment for processing images from teaching-boards acquired using portable digital cameras and cell-phones.

Keywords: *Digital cameras, image processing, portable cameras, teaching boards.*

1. Introduction

Portable digital cameras were developed for taking amateur "family photos"; the recent price-performance improvement, low weight, portability, low cost, small dimensions, etc. widened enormously the number of users of digital cameras giving birth to several new applications. One of them, completely unforeseen is using portable digital cameras for digitalizing images from teaching-boards. Teaching boards are present in every classroom throughout the world with small variations: modern ones are white and written with color felt tip markers; some others are black or green and written with white chalk sticks. Students take notes of what teachers write on the board for later revision. Today, some students start to take photos of classroom boards for later reference.

This paper describes a software environment to process images of teaching boards acquired using portable digital cameras operated either by students or teachers. This simple tool provides a natural way to generate digital content for courses, respecting particular aspects of the group such as syllabus, class learning speed, teacher experience, regional content, local culture, etc.

The system consists of three parts. The first is database formation. As soon as the images are transferred from the camera to the PC information is collected to generate a simple database that will organize the images for later content formation. Information such as teacher name, course name, discipline, subject, class number, group number, etc.

are requested. The second module is for image processing. This module will improve the image acquired in a number of ways involving background removal, image segmentation, skew correction, image enhancement, etc. The third part of the processing environment deals with outputting the content. Three different ways are under development: printed handouts, webpage generation and slide production. Each of these media receives the information of the processed image part of the environment and makes it suitable to its best use. This paper focuses on the image processing parts of the environment.

2. Image Acquisition

Image acquisition is performed by taking a photograph of the teaching board at a suitable distance, before cleaning up the information. Whenever a photo is taken, special care is needed to keep the readability of the text in the inbuilt camera LCD display. The image processing part takes the images acquired by a portable digital camera and processes them in a number of ways. Very often the photograph goes beyond the board size and incorporates parts of the wall that served as mechanical support for taking the photo of the document. Boards often have frames either made of wood or metal. The second problem is due to the skew often found in the image in relation to the photograph axes, as cameras have no fixed mechanical support very often there is some degree of inclination in the document image. The third problem is non-frontal perspective, due to the same reasons that give rise to skew. A fourth problem is caused by the distortion of the lens of the camera. This means that the perspective distortion is not a straight line but a convex line (in digital camera photos) or concave line (in cell phone photos), depending on the quality of the lens and the relative position of the camera and the document. The fifth difficulty in processing board images acquired with portable cameras is due to non-uniform illumination. White boards have a polished surface to avoid the marker ink to be absorbed by the board surface. This yields non uniform photo illumination as one often finds high intensity bright areas that correspond to reflections of room lighting. Figure 1 presents an example of a white board photographed

with a low-cost mobile phone Nokia 6020, where one may observe the four problems aforementioned: extra borders, image skew, non-frontal perspective distortion, and lens distortion. Besides those problems one may add: uneven multiple source illumination and non-delimited areas. One must remark that all pictures taken for this study and presented herein were from real classes. In the case of the board presented in Figure 1, there is a written area in the top-leftmost area that belonged to a "previous" board area. The lecturer did not respect the board junction that imposes a natural area delimiter. The pictures were taken after lectures without previous information to the lecturer. If informed beforehand, lecturers ought to respect area separation to make easier board segmentation. What is most surprising is that despite the low resolution of the camera of the cell-phone and the non-ideal environment, the image obtained provides readable information.

The board image presented in Figure 2 also exhibits the four problems already described. The photo was taken without natural daylight interference and strobe flash (the HP iPaq has no internal strobe flash). Room illumination was from tube fluorescent lamps. One may notice that the lecturer respected the board junction as a content delimiter.
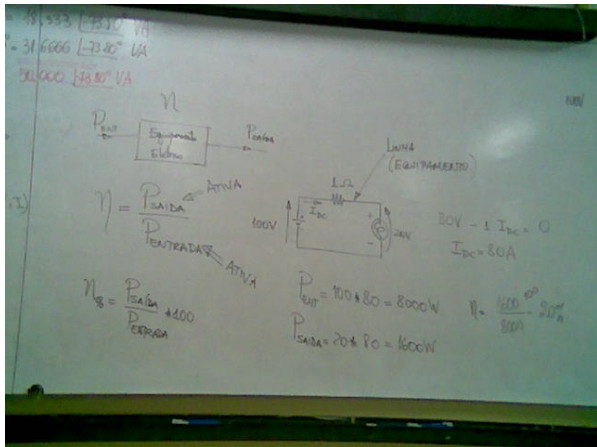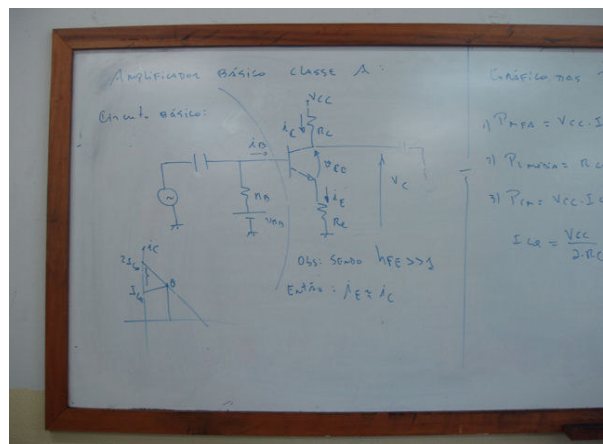

Figure 1. Part of a white-board acquired with internal camera of the cell-phone Nokia 6020, no strobe-flash used, 640x480 pixels, image size 21KB under Jpeg compression, board height 115cm, illumination: natural daylight (indirect) and ceiling tube fluorescent lamps.

An Olympus portable digital camera was used to acquire the board image presented in Figure 3. Two aspects are new in this image. The first is the presence of some blurred areas due to imperfect board cleaning or aging of surface of the board. The second is that the lecturer used vertical lines to split the content of his presentation on different board segments.
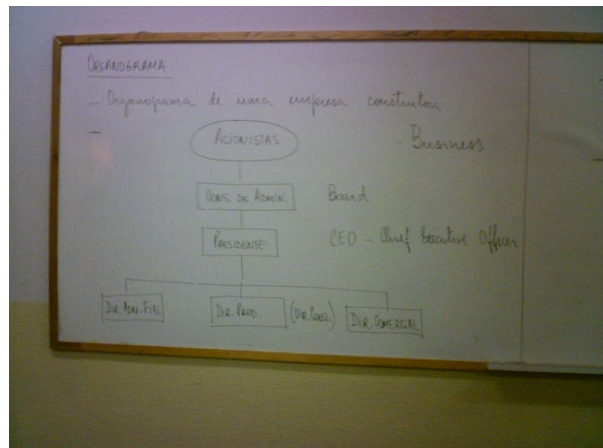
Figure 2. Part of a white-board acquired with internal 1.2 Mpixel camera of a HP iPaq rx3700, no strobe-flash used, image size 131KB under Jpeg compression, board height 115cm, illumination: natural ceiling tube fluorescent lamps.

Figure 3. Part of a white-board acquired with portable digital camera Olympus C60, 6.0 Mpixels, no strobe-flash used, image size 1.20MB under Jpeg compression, board height 115cm, illumination: natural ceiling tube fluorescent lamps.

3. Boundary detection

The first step to process teaching board information is to find the limits of the image. As already mentioned, boards often have frames as a decorative "finishing" or mechanical support as may be observed in figures 2 and 3, but that is not always found. Figure 1 is an example of the latter case. Besides that, in real classrooms a board is several meters wide. Thus, the content of a board often claims for several photos to be covered. Figures 2 and 3 exemplify a left section of a board while Figure 1 presents a central slice of a board. One should observe that the non-framed edges bring a

higher-complexity for boundary detection, thus for image segmentation.

Boundary detection is central for all other steps described herein because it isolates the area of interest from its surroundings. Besides that, the detection of the boundaries will allow one be able to correct perspective and skew in the image. Unfortunately, boundary detection has shown itself a much harder task than one may first assume. The algorithm presented in reference [8] [9] used to remove the mechanical background from document images acquired with portable digital cameras is unsuitable for board images, despite the high degree of similarity in the two problems addressed. A new algorithm is presented herein, performing the following steps:

3.1 Segmentation

1. Split the input image (ORI_IMG) into 4 regions as presented in Figure 7
2. Create a new binary image (DIF_IMG) of equal dimensions;
3. H_DIST and V_DIST are defined as functions of the image resolution. They correspond to the rounding-off of the integer part of 0.91% of the width and height in pixels of the original image, respectively. For instance, in the case of a 640x480 pixel image, H_DIST=6 and V_DIST=4.
4. DIF_IMG(x,y) is white if one of the following condition holds, it is black otherwise:

- The difference between each component of ORI_IMG(X,Y) and ORI_IMG(X±H_DIST,Y±V_DIST) is less than 10
- The componentwise gap of ORI_IMG(X,Y) and ORI_IMG(X±2.H_DIST,Y±2.V_DIST) is < 10.
- The pixel differences are local operations, which minimize non-uniform illumination. A difference between non-board areas and board areas is more likely to turn black in DIF_IMG, than if all pixels compared belong to the board.

Two pixels differences are needed to minimize the "double contour" around board writings. The first contour is marked as black when ORI_IMG(X,Y) is located on the teacher writing and the inner pixel is a board background. The second contour is the other way round, thus DIF_IMG is wrongly marked as black. Such behavior may be seen in Figure 5 for the letter "A" obtained from Figure 3. The behavior when considered the two differences is shown in Figure 6.
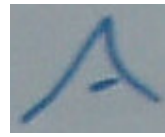
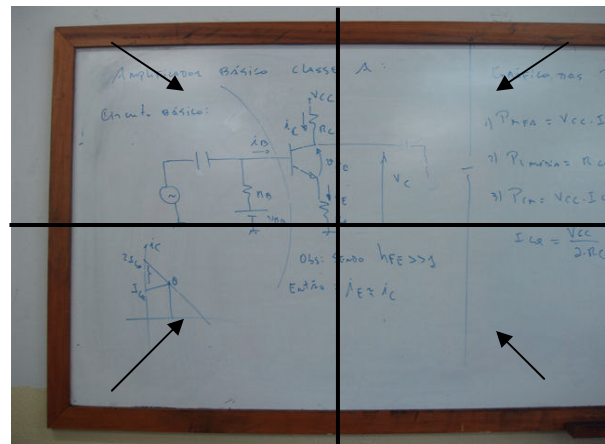**Figure 4.** Letter "A" extracted from Figure 3

**Figure 5.** Segmentation considering just one difference

Figure 6. Segmentation considering the two differences

The sign is such as always to subtract the outermost value from the innermost one, according to the matching position from the region on Table 1.

Figure 7. Board split into four regions. Arrows show the direction of illumination compensation.

The result of Step 1 applied to the image presented in Figure 7 is shown in Figure 8.
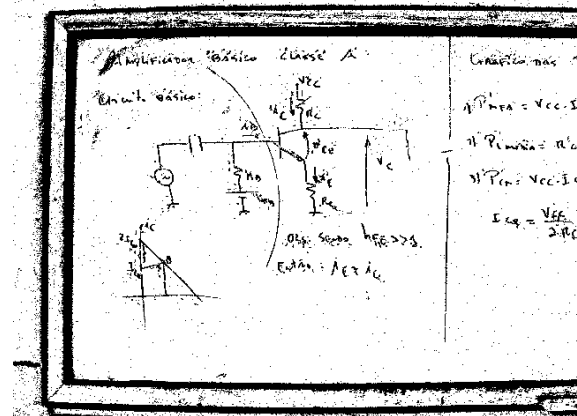
Figure 8. Figure 3 board image after Step 1.

Table 1. H_DIST and V_DIST offset calculation.

X+H_DIST, Y+V_DIST	X-H_DIST, Y+V_DIST
X+H_DIST, Y-V_DIST	X-H_DIST, Y-V_DIST

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3.2 Finding Control Points

Points that possibly belong to the board boundaries are called control points. This step will try to spot them by analyzing the binary image.

For each direction, N equally spaced axes are defined to scan the binary image looking for control points from the centers towards the borders. Each of those vertical axes is swept with a 7x1 pixel mask. Similarly, each horizontal axis is scanned with a 1x7 pixel mask. If four or more pixels under the mask are black, go to 2. For the collected images N was set up to 9.

1. Calculate colors ratio in the rectangle around current point (X, Y). The bottom border of the rectangle has the upper left corner located on (A,B) and the lower right corner on (C,D), where:

$$A = X - \left\lfloor \frac{IMG\_WIDTH}{N} \times \frac{1}{2} \right\rfloor$$

$$B = Y - IMG\_HEIGHT \times INTERNAL\_CHECK$$

$$C = X + \left\lfloor \frac{IMG\_WIDTH}{N} \times \frac{1}{2} \right\rfloor$$

$$D = Y + IMG\_HEIGHT \times EXTERNAL\_CHECK$$

   * Where INTERNAL_CHECK=0.165% and EXTERNAL_CHECK=0.91%

2. If within the rectangle (A,B,C,D) there is more than 65% of black pixels, then (X,Y) is marked as a control point candidate for the bottom border. Otherwise, the algorithm moves outwards looking for another candidate.

For all other directions the algorithm works similarly to the step explained above. An example of control points found for the board image in Figure 8 is presented in Figure 9.
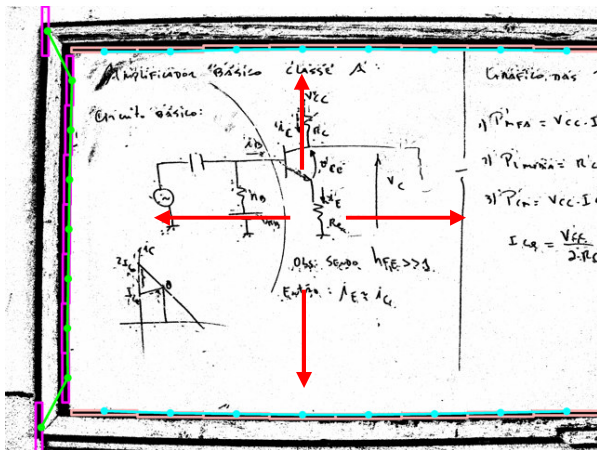
Figure 9. Board image from Figure 8 scanned in red from the center towards the outwards exhibiting the control points on top-bottom-left positions.

3.3 Control point elimination

Control points can be wrongly found, due to:
- The ORI_IMG(X,Y) it is out of the boundary of the board, as shown in Figure 9;
- When the board has added "noise" such as a sign or advertisement;
- The board picture was taken with strobe flash, etc.

To eliminate such points the following procedures are executed:

1. For every control point candidate, tangents of the angles (Θn) with the border axis formed by the candidate and its 2-neighborhood in both sides are calculated. A candidate is selected if the absolute value of at least 2 tangents is lower or equal to 0.07. One may observe that this calculation is not relative to the number of the neighborhood, so if the candidate is the outermost point all tangents should be lower or equal to 0.07. An example of a horizontal border neighborhood is shown in Figure 10, where the candidate is in dark grey.


$$\tan \Theta_{-2} = H_{-2} / W_{-2}$$
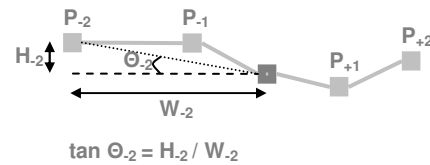
Figure 10. Control point selection

1. After executing step 1 above in all directions, the outermost points will define a line segment as depicted in Figure 11. Any candidate to a control point outside the orthogonal segment defined is excluded.
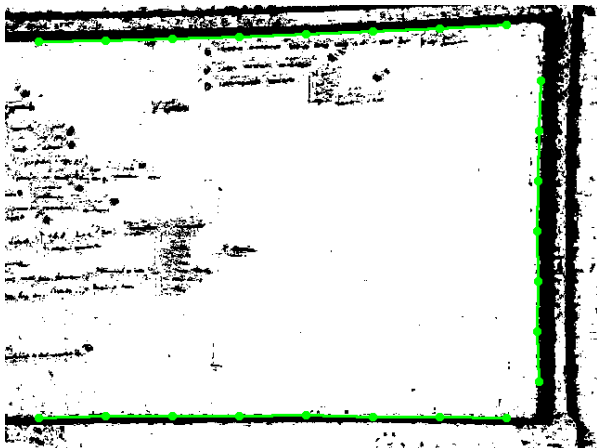
Figure 12 shows control point candidates. Figure 13 shows the image after the deletion of the wrong ones.
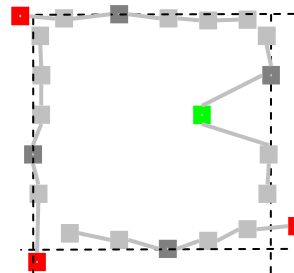
Figure 11. Green CP is eliminated in step one, while red ones are eliminated in step two.
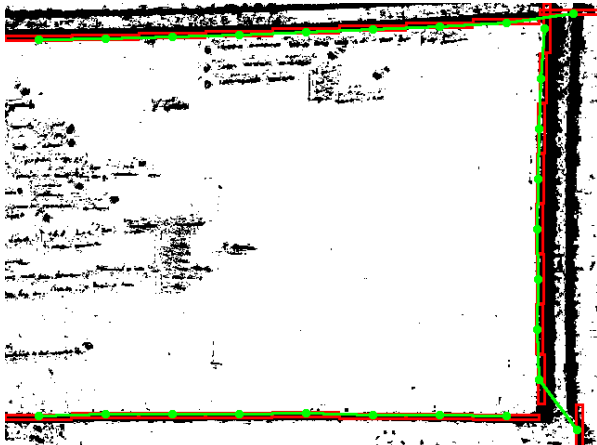
Figure 12. Board image showing two wrong control points that are deleted.

**Figure 13.** Board image after control point elimination.

4. Perspective Correction and Cropping

The freedom allowed in acquiring board images with portable digital cameras without mechanical support invariably leads to perspective distortion. Perspective transformation must be done in order to make the image appear as a frontal vision. This process is called rectification [1] [3] [4] [5] [6] [10]. Four edges that delimit the original board image are needed. There are four kinds of board images:

1. The image presents no lateral borders as presented in Figure 1.
2. The image presents a left border on the image, as shown in Figures 02 and 03.
3. The image presents a right border on the image.
4. The whole board image fits the photograph.

In any of the cases above four points were taken as reference for perspective correction. Those points were chosen by drawing a line passing through the two outermost points in each direction and finding their intersections, which are named the *reference points*. If no control point is found in any direction the intersection of the lines drawn with the end of the image is taken as a reference point. This often happens in the three first cases above.
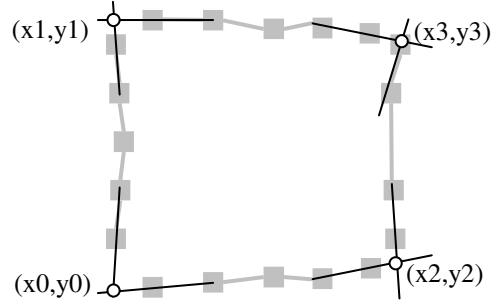
**Figure 14.** Reference points for perspective correction

One must remark that the technical literature registers other perspective correction techniques in the absence of reference points [4]. The adoption of the choice of reference points as above was done for a matter of uniformity and simplicity, and provided good results as is discussed later on.

Once the four reference points are chosen their equivalent after perspective correction are calculated as:

```
d1=|x0-x2|+|y0-y2|; d2=|x1-x3|+|y1-y3|;
d3=|x0-x1|+|y0-y1|; d4=|x2-x3|+|y2-y3|;
aspect=(d1+d2)/(d3+d4); x'0=x'1=x0;
x'2=x'3=xd0+d1; y'0=y'2=y0;
y'1=y'3=y'0+(d1/aspect);
```

5. Image Enhancement

There are several algorithms in the literature for enhancing images. Image board enhancement has to increase the contrast between the teacher writings and the board background, increasing information readability. Finding a way to cluster similar information to widen the gap between the different clusters is the key to image enhancement in the case of teaching-board images.
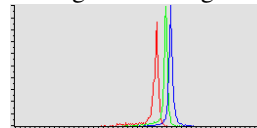
Figure 15. Background histogram of Figure 04
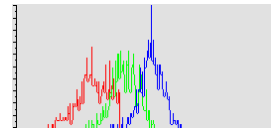
Figure 16. Histogram of Letter of Figure 04

Figure 15 and Figure 16 present the histograms of different selections of Figure 04. The letter "A" has a more representative contribution of the blue

component, and the color-histogram is widespread. The background histogram is narrower and more uniform. An efficient way to increase the contrast, without affecting the feature of an image, is provided by Rayleigh filter [7].

The images were tested against the following classes of algorithms: global and local histogram equalizations sharpen, and mathematical morphology techniques [7]. The Rayleigh filter with parameter λ= 0.5 consistently provided the best results. Figures 17 to 19 show images after Tableau processing.
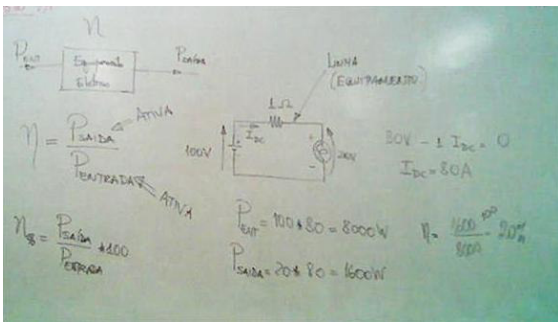

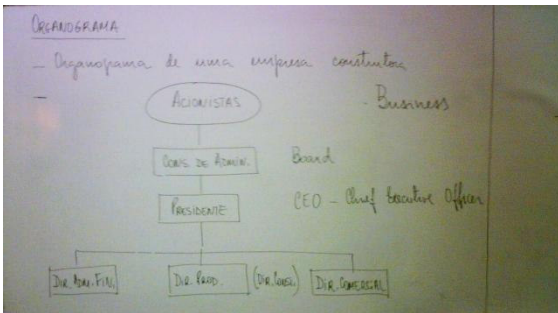**Figure 17.** Tableau applied to Figure 1

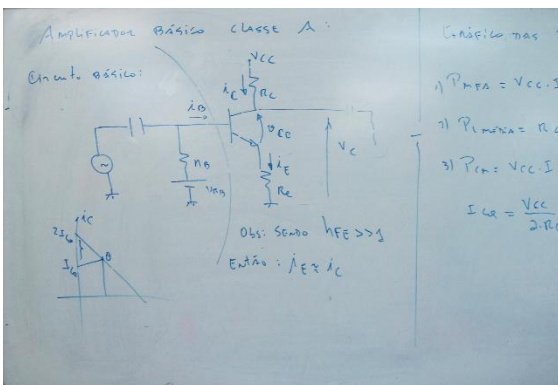**Figure 18.** Tableau applied to Figure 2

Figure 19. Tableau applied to Figure 3

6. Tableau in ImageJ

ImageJ [11] is an open source image processing environment in Java developed by Wayne Rasband, is at the Research Services Branch, National Institute of Mental Health, Bethesda, Maryland, USA.It allows the insertion of plug-ins for special purposes. The algorithms presented herein for processing teaching board images was developed as an ImageJ plugin. Figure 20 presents a screen shot of the Tableau interface menu.
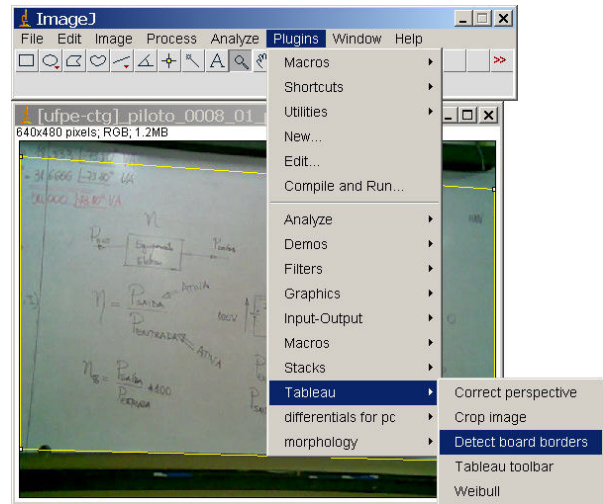

Figure 20. Tableau Plug-in interface in ImageJ

The algorithm for border detection presented above sometimes does not yield the best choice. The Tableau plug-in in ImageJ allows the user to adjust the contour detection for better processing.
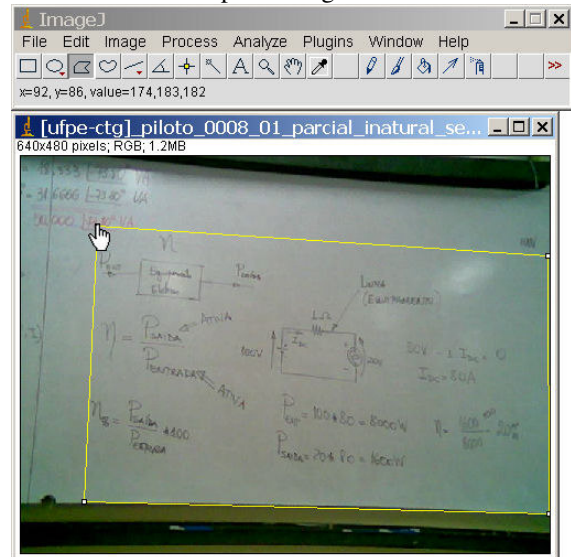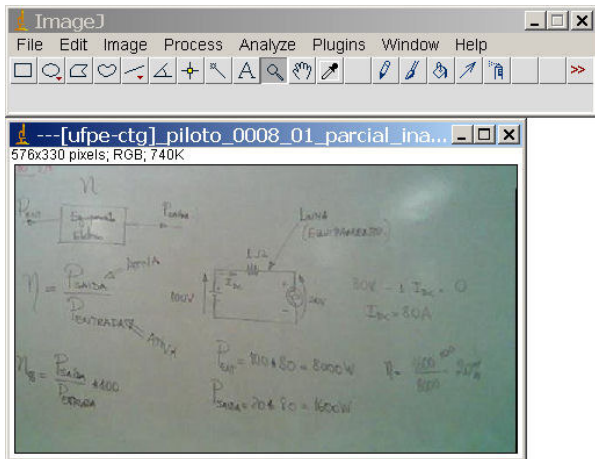

Figure 21. Boundary corrected for Figure 1.

Figure 22. Perspective corrected and
cropped image from Figure 21.

Figure 20 presents the automatic boundary selection performed by the algorithm in the background, while Figure 21 shows the operator driven selection for the same image. The perspective corrected/cropped image is in Figure 22. Image in Figure 1 has size of 27.5 Kbytes while the cropped image claims only 15Kbytes of storage space, both compressed in JPEG. Average times for each of the board processing phases are showed on Table 2. They were measured considering the end-user perspective, thus screen refresh and progress bar updates are included in processing times.

Table 2. Average processing times in ImageJ

| Tableau	6.0 Mpixel	1.2 Mpixel	300 Kpixel
Border detection	361ms	104ms	22ms
Persp. correction	42857ms	9692ms	2187ms
Image crop	589ms	224ms	79ms
Rayleigh ($\alpha = 0.5\sqrt{2}$)	515ms	198ms	60ms
Total time	44322ms	10218ms	2348ms

Times were measured on processor AMD Sempron 2600+ 1.83 GHz with 512Mb RAM running on Windows XP SP2. One may see that perspective correction in Tableau is very time consuming. This is due to the use of the JAI (Java Advanced Imaging) version 1.1.3 with machine native support [12] which is not incompatible with ImageJ, demanding to-and-from conversion of representations of the two libraries. The development of an ImageJ plug-in for such purpose will certainly yield more efficient code. Bicubic2 interpolation with subsampled bits equal to two was used [1]. One may see that the Rayleigh algorithm

takes longer to process than the Border detection algorithm. This is due to the image refreshing window needed by Rayleigh while detection only shows the selection of board corners to the user.

Tableau was tested on 81 images from Olympus C60, 53 from Nokia 6020 and 3 from HP iPaq rx3700.

7. Comparisons with other approaches

Tableau was compared with two document processing web environments: Qipit®[13] and ScanR®[14]. The former was tested with 16 Olympus images, 3 from HP iPaq and 6 from Nokia 6020. The latter was tested on a subset of those images, as ScanR does not handle low-resolution images such as the ones taken with the Nokia 6020. Typical comparative results for the board of Figure 23 may be seen in Figures 24 to 26, working in similar circumstances.
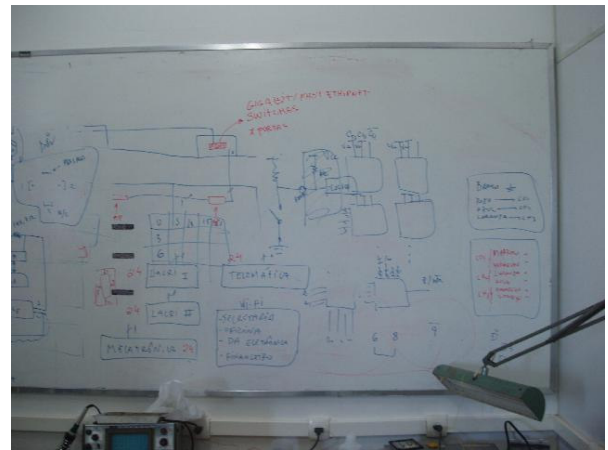
Figure 23. Original image
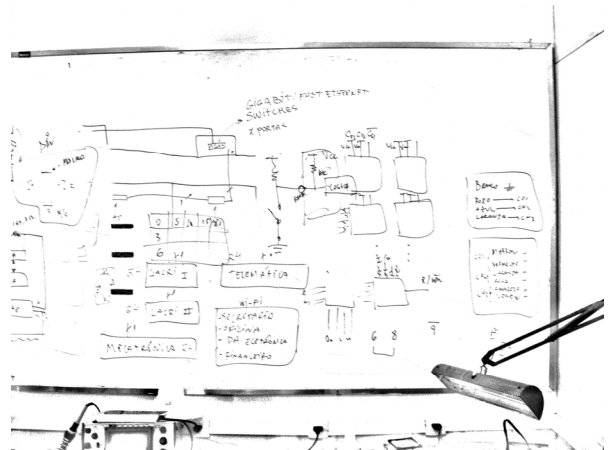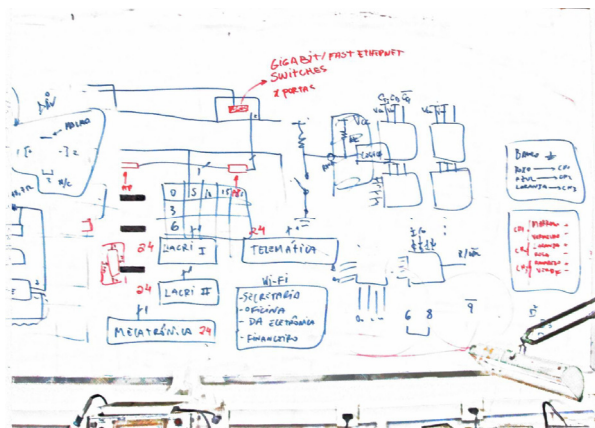

Figure 24. Qipit® processing
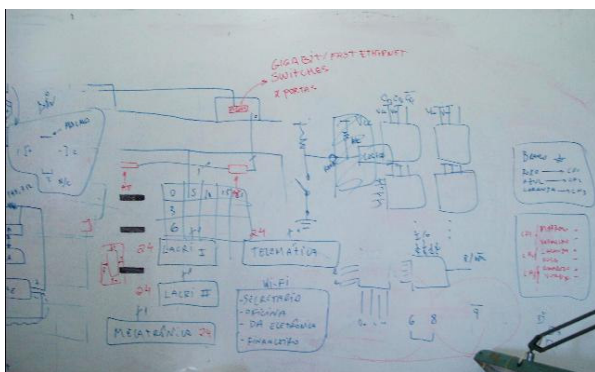
Figure 25. ScanR® approach

Figure 26. Tableau approach

As Figure 24 shows, Qipit neither detected the board border nor corrected the perspective, but binarized the image. ScanR, as Figure 25 shows, performs a poor border detection and crop, but a good image enhancement. Tableau, as shown in Figure 26, presents the best border detection and crop of the tools studied, but image enhancement falls behind ScanR. Performance comparison could not be done because both Oipit and ScanR systems are on-line Internet services.

8. Conclusions and Further Works

Portable digital cameras are a technological reality today that opens a wide number of challenges in image processing, including board image processing. This paper presented the image processing part of Tableau, an environment for assisting the layman to easily generate digital contents from teaching-board images. The image processing part of Tableau was implemented in ImageJ and finds the edges of board images, allowing perspective correction and image cropping, thus eliminating wall background and board

frames. All images analyzed here were obtained from real classrooms without any special care either from lecturers or from the environment (illumination, special framing or marking, etc.). Different cameras were tested (different manufacturers, resolution, quality, etc.). Whenever compared with Qipit® and ScanR®, Tableau provided the best image segmentation and cropping.

Better board image enhancement and image binarization are currently under work in Tableau.
The Tableau code is freely available at: http://www.telematica.ee.ufpe.br/sources/Tableau.

9. Acknowledgements

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[14] Scanr®. http://www.scanr.com

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