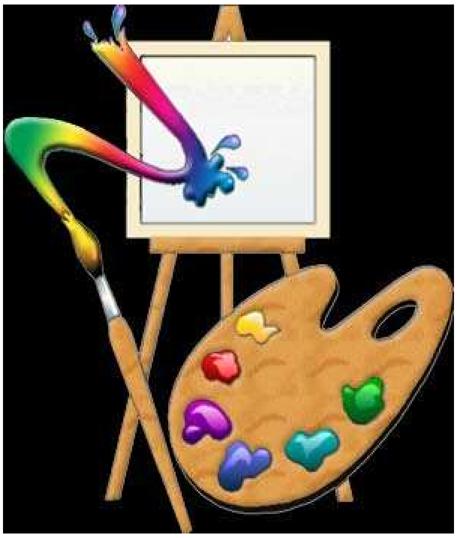
Aalborg University, Department of electronic systems
9th Semester

Paint
Multi-touch table



Project group: 921

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Abstract

The tabletop display is a more and more commercialised touch screen system. It is the subject of many studies in laboratories. The principle of the touch screen is constantly developed and improved to create user-friendly applications.

An existing experimental tabletop from Aalborg University is the starting point of the following project. This project improves the components of the tabletop and the finger detection tool from its lack of performance in terms of speed and accuracy. An entertaining drawing application demonstrates the new properties and qualities of the tabletop display.

Acknowledgement

This report is the synthesis of a project which ran six months. That is why we would like to thank all the people who help us for the outcome of this project.

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Chapter 1

Introduction

This chapter introduces the multi-touch table and his principle. It also explains in which context the Paint table is created and finally exposes what are the objectives.

1.1 Context

Usually, users find it easier and more pleasant to use an interactive surface instead of a classical mouse, touchpad or keyboard. Indeed, it often allows users to have a convenient control. It is a more natural gesture which means that users are more concentrated on the action to carry out instead of the device.

The creation of the first multi-touch table dates from1982. Since then, many firms tried to develop this technology and make new applications. It is still is a very active area of research [1]. The principle is based on a machine-human interaction technique. The multi-touch table is made up of a touch screen which recognizes some contact points as well as software which analyzes these contacts.

Figure 1 - Multi-touch table [2]

For this project, we use an existing touch table which was made by some previous students at Aalborg University. The device includes a table with a transparent surface, a projector to show the interface, a camera to make the finger detection, a light to illuminate the surface and a computer. The idea of this project is to improve the light source and the finger detection on the table's surface. A paint application should be also created to demonstrate the system.

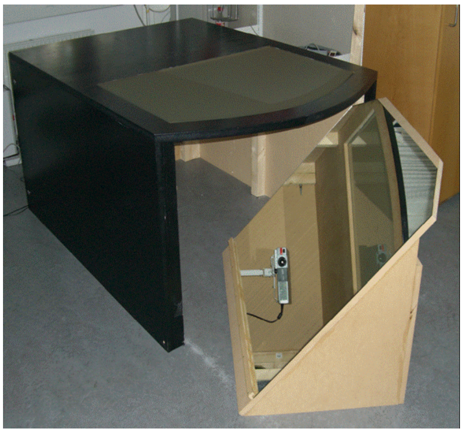


Figure 2 - AAU 's table

The use of whiteboards is very spread in the working world and especially in the meetings. Indeed, it allows someone to give better explanations by using drawings and diagrams. It is very easy and fast to use. But one of its drawbacks is that it is not possible to do modifications on drawing and save them. That is why a digital version is really interesting.

1.2 Objectives

The aims are:

- To improve the general and physical structure of the tabletop display. This point includes the lighting of the table and the position of the elements below the table. The different issues and solutions will be explained in the next part.

- To improve the software. The purpose is to have a faster video processing engine than the existing one. It has to be more compatible with all elements of the table (for example with the camera).

- To make a drawing application with a user-friendly interface. The user will be able to draw and save his work. This application will be inspired by the Microsoft Paint.

To carry through this project and to achieve these objectives, it is necessary to study the previous project, to analyse the context and find some solutions and ideas to build this new project. After the set up of all the elements (table’s structure, finger detection tool, drawing application), the system should be tested and a feedback with the conceivable improvements should be made. All this steps are described in this report.

Chapter 2

Preanalysis

This chapter analyses briefly the previous projects. The elements which should be keep and improve are deduced from this analysis. This step allows the members of the work group to have good ideas for the creation of this project.

2.1 Previous projects

2.1.1 Tabletop display

The previous projects used an existing tabletop display which was available at the laboratory in Aalborg University. It is made up of several elements which are describes in the following part.

Tabletop

The table is a wooden table. Half of the table is round and is made up of a transparent window glass where the graphical interface is projected. This glass is covered by a plastic surface which allows us to keep more light on the table's surface. Therefore, we get a better image quality.
The particular design of the table was made for a 3D graphical application. Unfortunately, it is not convenient for a Multi-touch table. Indeed, the projector displays a rectangular image which is hardly compatible with a semicircle.

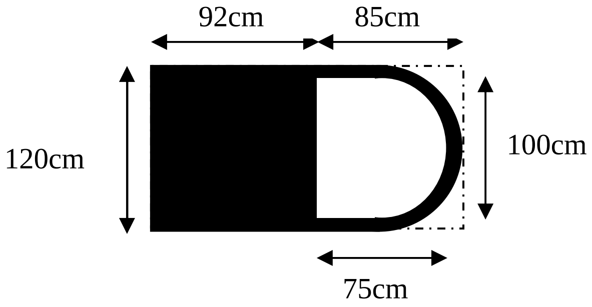


Figure 3 - Tabletop display design

Projector

It is required to project the graphical environment.

Mirror

It is not possible to put the projector and the camera just below the transparent surface. The dimensions of the table are not suited to this configuration. The projector and the camera are moved back and a mirror is inserted bellow the table's surface. This mirror gives the possibility to reflect the light of the projector. The camera can watch correctly the surface.

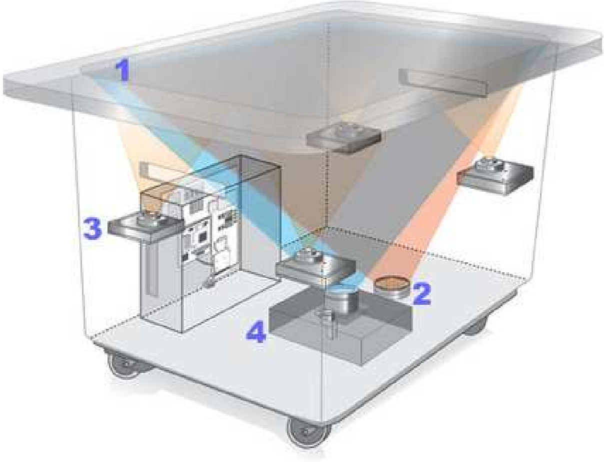


Figure 5 - The ideal layout [3]

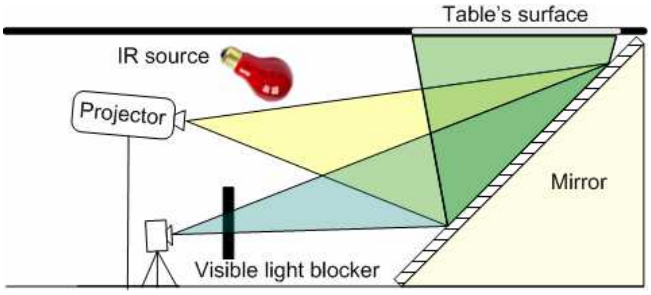


Figure 4 - The actual layout

Light

The wish is to acquire the position of eventual fingers without the graphical interface. To avoid this displayed image of the projector, the solution is to switch the camera's colour domain from visible light to infrared light. The information displayed on the table's surface belong to the visible light domain. Therefore it is necessary to acquire only the infrared signal with the camera. That's why a visible light blocker was put in front of the camera (see figure 4). To increase the amount of infrared light reflected by the fingers, a source of infrared light was added. This source was made up of two bulbs which also diffuse a small amount of visible red light. To compensate this problem, two red light filters were used.

Camera

The previous project chose to use a web-camera because web-cameras are cheaper compared to a digital video camera which needs to be connected to a computer via a frame grabber. Most of the web-cameras include an internal frame grabber and allow USB or FireWire connectivity. The camera Unibrain Fire-I^{TM} was used because it was a good compromise between the price, the image quality and the transfer speed.

Figure 6 - Camera Fire-I^{TM}

2.1.3 Programming choice

The programming language used to build the system was the Java^{TM}. This choice was made because the Java^{TM} Media Framework allows good camera manipulations. Therefore it was easier to make the finger recognition engine. Once this part was built, it was natural to include this part in a Java application to make a homogenous system.

2.1.3 Image processing

This part is a succession of operations which are used in the previous projects. They are applied to the images recorded by the camera to detect the fingers.

Calibration

The first thing to do is the camera-projector calibration. Indeed, the use of a mirror creates a distortion angle. This involves that the projector's coordinates are different from the camera's coordinates. In an ideal and to avoid this problem, the projector and the camera should be set up in the same location and with their lens in the centre of the configuration. Unfortunately, it is not possible. The solution is to find a function which allows the user to calculate the difference between the horizontal lines displayed by the projector and the ones recorded by the camera. The same rule is applied to the vertical lines. A fourth degree polynomial is used to make this interpolation. With this manipulation, it is possible to switch from the camera's system to the projector's system.

Acquisition of the frame

The camera records the table's surface images which are called frames. The first transformations to detect the finger are made from the current frame. The first step is to divide it in several windows (40 x 30 pixels).

Brightness enhancement

The infrared lights used to illuminate the table's surface don't create a uniform lighting. Because of this phenomenon, some areas will be darker and the finger in these particular areas won't be so reflective. It will be more difficult to detect them.

That is why it is necessary to use the operation called brightness enhancement. This step consists in normalizing all the pixel values in each window.

Each pixel value will be multiplied by a factor which transforms the highest pixel’s value in 255. After this, all the probable fingers will appear brighter.To not normalize the dark areas which don’t contain a finger, a threshold ε_{Br_E} is introduced. Indeed, for the dark area without finger, the factor is very high. Therefore, this threshold allows us to keep only the windows where the factor is less than this threshold and transform the others in black windows.

Subtraction

The aim of the subtraction is to make the difference between the current image and the reference image. This procedure allows the user to detect the foreground objects. This subtraction is only applied in the previous windows that we keep.

Binarization

Another step is the binarization. It is an operation which transforms the image in a black and white image. To do so, a threshold ε_B is used. All the pixel’s values below the value ε_B are changed in black, the ones above, are put in white.

Holes’ removal

After binarization, the fingers look like discontinuous spots. Thus, this step consists in creating continuous areas.

Spots creation

This stage is the last one to get the spots which maybe correspond to the fingers. The purpose is to look all the close neighbours (8 pixels) of a pixel. If they are white, they are added to the previous spot.

Discard Size

To be sure that all the spots that we observe are a finger, it is necessary to check a last feature: the size. Indeed, if the size of a spot is too big or too small, it might be noise and it is removed.

2.1.4 Applications

Music application

The idea of this project is to use and navigate through a music library where the songs are categorized not with a type but with colours.

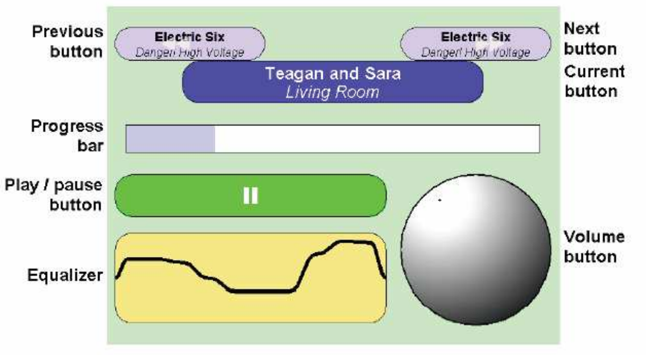


Figure 7 - DemeTouch interface

Piano application

This project is based on the same image processing part but implements another application. The aim was to offer an interface which allows a user to play piano. The keys change colour when they are pressed and the user can hear the corresponding sound.

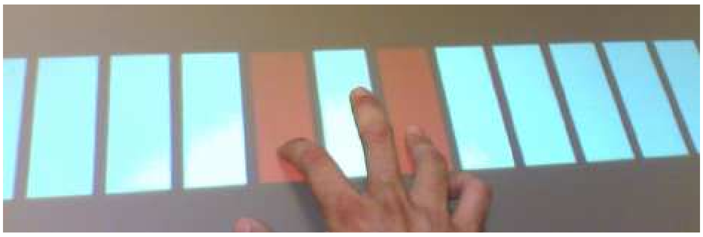


Figure 8 - Pianotable interface

2.2 Paint project

The aim of the work is to improve the existing table’s structure and the tool for the detection finger and to create a new application.

Therefore, the work began with a study of the possibilities the previous versions of the multi-touch table offered. To do so, it was necessary to read a lot of documents and to try to run the old projects. This step gave a good idea of the functionalities available from the old projects and which contribution it was possible to provide.

Besides, a reflection about computer languages was required. The choice of these languages, improvements and innovations will be explained in the followings part.

During the project, a meeting took place once a week to discuss the progress of the work and to try to find solutions if there were some problems.
See the following schedule for details:

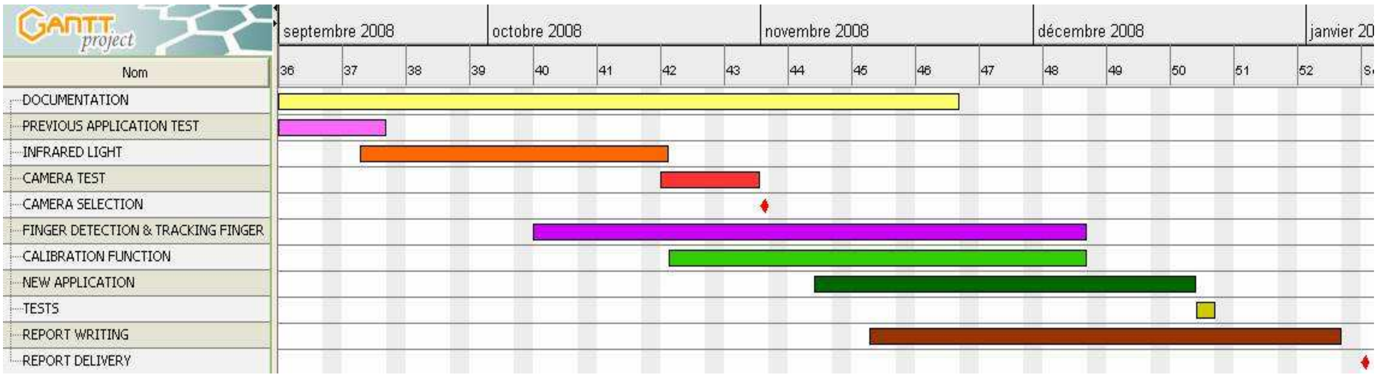


Figure 9 - Schedule

2.2.1 Tabletop display

The main structure of the previous tabletop is kept. But it was decided to improve the source of infrared light. Indeed, the two infrared bulbs also emit in the visible red spectrum and become very hot. Then, they also require a lot of energy. The last drawback is that they create speculars in the acquired image.
The idea to correct this problem is to use infrared LEDs instead of these bulbs.

2.2.2 Programming choice

It was decided to use the language C++ to build the image processing part. This choice was made because the Java language didn't allow us the use camera on the computer available in the laboratory.
Then, it allows us to use the library OpenCV (Open Computer Vision Library) which offers many possibilities concerning the acquisition, the image processing and the display of images in graphical windows.
The application is written in C sharp (C#). This language was selected because of our knowledge of it. Furthermore, it is compatible with the language C++.

2.2.3 Image processing

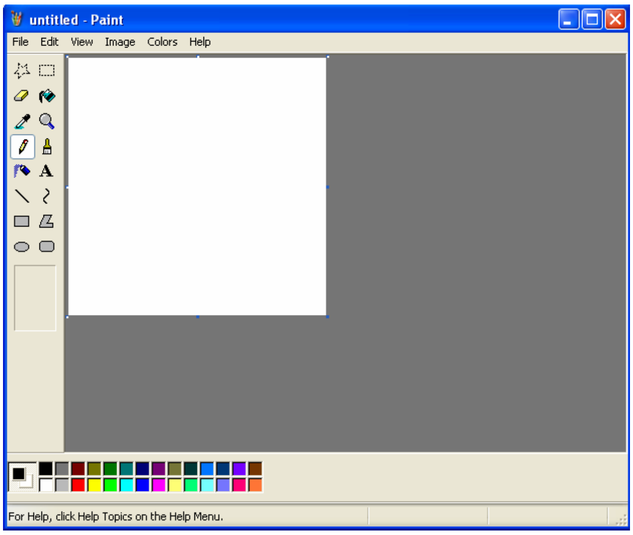
The image processing part of the previous projects was analysed and one of the aim of this project is to improve it. Of course some steps will be kept as the acquisition of the reference image, the subtraction… but some of them will be removed and some other added in order to make the system better. Then, the order in which the operations took place will probably not be followed. For example, it is more common, to begin which the subtraction and to work on the subtracted image instead of the current image.

2.2.4 The application's idea

The application's idea is based on Microsoft Paint which is a simple graphics painting program. The interface will contain an area which will be viewed as the work space. It is in this area that the painting actions will be made. Here are the different options that the software will offer:

- To draw: the user has at his disposal two main features. First the pallet which is the colour's range. The second is the tool box. It allows the user to select the type of utensil that he desires to draw (pencil, brush, airbrush, text, pre-defined shape: rectangle, ellipse…). Each time, the choice of the colour and the tool will be displayed in a specific area to allow the user to remember easily his choice and to facilitate the drawing for him.

- To open and save an image.



For Help, click Help Topics on the Help Menu.

Figure 10 - Microsoft application

Chapter 3

Analysis

This chapter analyses the problems, the different possibilities and chosen solutions for the development of this project. This part concerns essentially the configuration of the table and the image processing tool.

3.1 Infrared light

A camera which is able to see in the visible spectrum, will perceive the fingers but also the projected image on the table's surface. The aim is to detect finger. Therefore, it is easier if it is possible to avoid the view of the projected image. Indeed, it is simpler to work on the image with only fingers.

It turns out that the projector emits light only in the visible. That is why the solution is to choose a camera which is sensible to IR (InfraRed) light. In the previous project, it was realized that the ambient IR light was "not sufficient to provide enough contrast for any kind of computer processing". That is why it was decided to add an artificial IR light. The solution was to put two high power IR bulbs, one at each side of the table.

Figure 11 - IR bulb

It was noticed that these two bulbs also emit in the visible red spectrum that is why it was put a green transparent plastic in front of the bulbs to filter this visible light.

The drawbacks of using this solution are that the bulbs become fast very warm and they consume a lot of energy. Then they produce two speculars in the acquired image. It is necessary to take it into consideration and remove them during the image processing.

Therefore it was necessary to find a better solution to produce IR light and the solution with IR LEDs was chosen. Here are the advantages of using LEDs:

- they produce more light per watt than incandescent bulbs so they consume less
- they don't become warm
- they are small therefore it is easier to place in such a way we don't have the speculars

The approach to build this new infrared light will be explained in the following chapter.

3.2 Projector

As said in the last part, the speculars due to the infrared light can be avoided. But the one due to the projector remains. To attenuate or to remove this specular, it could be necessary to put another surface on the lower part of the glass window. The idea is to turn over the glass window which already owns such a surface on is top.

3.3 Camera

As said in chapter 2, the camera used in previous projects is the web-camera Unibrain Fire-I^{TM}. Unfortunately, there was a problem of incompatibility between the Java language and the camera on the available computer.

Some tests with other cameras were made. The first test was made with the Philips PCVC840K/20 camera. But it was too slow to follow the movement of the fingers. For the second test, the Philips SPC-225NC camera was used. This web-camera contained an IR filter, which was removed from the lens of the web-camera. This camera was fast enough but the resolution of the camera was low which involves that the position of the fingers was interpolated.

Finally, the solution was to keep the Unibrain Fire-I^{TM} camera and to use the language C++ instead of the Java^{TM} as explained in the part 2.2.2.

3.4 Image processing

A good processing engine should be fast. It is necessary to have a good latency-free response from the system to the user command. Indeed, the user needs to see what he is drawing in real time in order to work continuously. This feature depends on the type of the camera but also on the image processing part. The following paragraphs will explain the important steps to know for the image processing engine of this project.

3.4.1 Basic notions in image processing

The first thing to know is how an image is represented. Most of the time, an image is symbolized by a matrix. For an image in a gray scale format, this matrix contains numbers between 0 (black) and 255 (white).

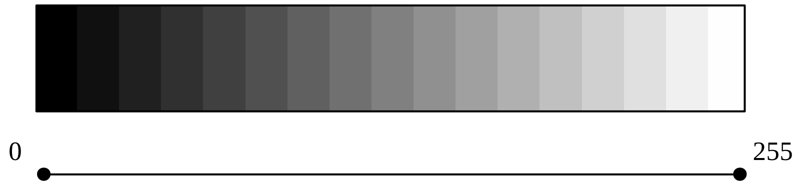


Figure 12 - Gray scale

Usually, computers consider this matrix as a one-dimensional array. To get a pixel's coordinates from the matrix to the one-dimensional array, it is necessary to use the following equation:

$$x_{array} = x_{matrix} + \text{imagewidht}^{*}\ y_{matrix}$$

There are several types of operations that we can use on the original image: point operations (use only one point), local operations (use one point and his neighborhood), and global operations (use the whole image).

For this project only the two first operations will be used. Indeed, the last one supposes that we have certain knowledge of the detected objects.

3.4.2 Information about the table's surface

The image which comes from the camera also includes a part of the wooden table and not only the glass window. The aim is to save time which means to not make any calculations on pixels of the wood. It was noticed that if the table's surface is covered with for example a paper, there won't be a big change concerning the light intensity for the wood contrary to the transparent surface. This feature will be used to determine where is the wood in the recorded frames.

3.4.3 Subtraction

The subtraction is necessary to detect the foreground objects. This means to make the difference between the current image and the reference image. This procedure is a pixel-by-pixel operation. Let $I_C(x, y)$ the current image, $I_R(x, y)$ the reference image and $I_F(x, y)$ the final image. The subtraction operation is given by the following equation:

$$I_F(x, y) = I_C(x, y) - I_R(x, y)$$

The negative pixel values which result from this operation are deleted because for most of them, it is noise.

The result of this subtraction is that all the zones which don't contain fingers will have the pixels set to 0. Unfortunately, the environment (illumination) is changing that is why the zones without finger of the current are never perfectly equal to the reference image. This feature introduces some noise in the final image.

To get a satisfying result of the subtraction, it is necessary to have a good reference image. For this project, this image, which is called background, is the one which is without fingers. The first couple of frames are not advisable to create the reference image. Indeed, the camera needs few seconds to acquire the right image (i.e. with the good lighting…). To know which frames we can use we will calculate how bright the image is. We keep the frames which are within the range plus or minus 5 percent of a pre defined threshold. As said before, this background is not usable all the time because the environment changes.

To get a good background, in order to remove the noise, it needs to be updated. Most of the time fingers appear on the frame. So, it is necessary to remove them from the image. First, the method consists in determining where the fingers are and then in defining the Region Of Interest (ROI) which contains the fingers. Then, the Goris-Watson algorithm is used to make the interpolation of the background. This method is applied in medical image processing (it is involved in the measurement of the myocardial perfusion). With this algorithm we try to figure out what can be below the object. To do so, an interpolation of the pixel values behind the ROI is made. In our case, the ROI was a rectangle as the next figure show.

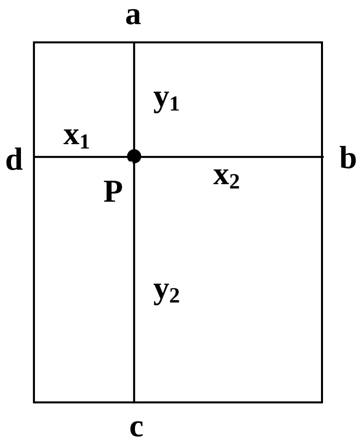


Figure 13 - ROI

The formula to get the value of the pixel P is:

$$P = \frac{\left(aw_a + bw_b + cw_c + dw_d\right)}{\left(w_a + w_b + w_c + w_d\right)}$$

Where:

$$w_a = y_2 \;/\; \left(y_1 + 1\right)$$

$$w_b = x_2 \;/\; \left(x_1 + 1\right)$$

$$w_c = y_1 \;/\; \left(y_2 + 1\right)$$

$$w_d = x_1 \;/\; \left(x_2 + 1\right)$$

And a,b,c,d mean the pixel values on the ROI’s border.

This algorithm was tested on a medical image. Here is the result:

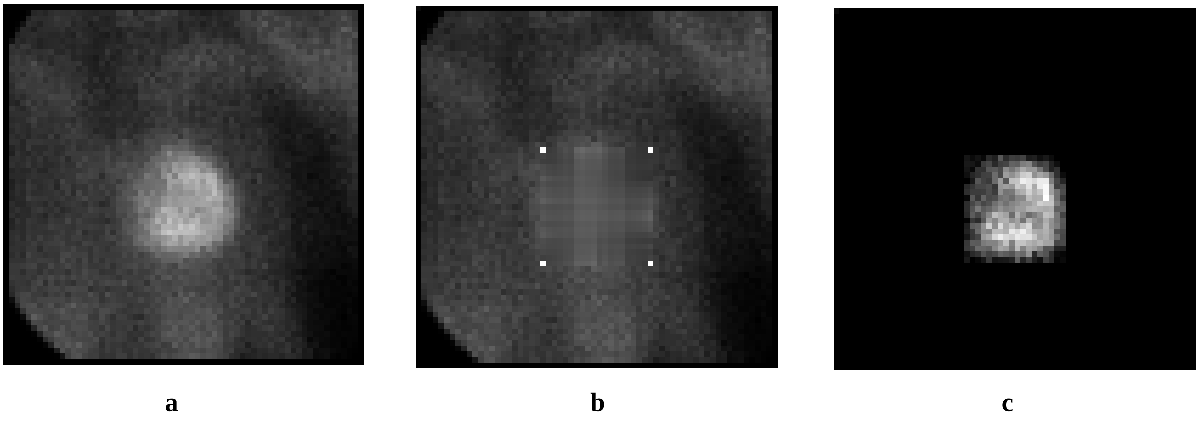


Figure 14 - Watson algorithm applied on a heart image - a) input image b) interpolated backgroung c) subtracted image

This algorithm gives a good result with the previous image. Unfortunately, there are some problems in using it with the tabletop display. The first one is that it requires a lot of computer power. Then, the glass window is not a rectangle, it has a circular part. Sometimes, a corner of the ROI is on wood of the table. The wood is as bright as a finger so it is considered as such. This involves some mistakes in the calculation. Because of the shape of the table, this solution is not optimum.

Another idea is to use only the frames during which the user doesn't touch the table's surface.

3.4.4 Brightness enhancement

The infrared part of the spectrum is used to detect the finger. Some infrared light are added because the ambient IR light is not sufficient to provide enough contrast. Unfortunately, the distribution of the light on the surface's table is not completely uniform. This involves that in some areas, the fingers are less reflective.

The aim of this operation is to adjust pixel values to not discard the fingers which are in the dark areas.

The following equation is used:

$$i_{(x,y)} = \phi . i_{(x,y)} \text{, where } \phi = \frac{255}{\max i_{(x,y)}}$$

The purpose is to normalize all the pixel values in each window. Each pixel value will be multiplied by a factor which transforms the highest pixel's value in 255 and the lowest in 0 as you can see in the following example.

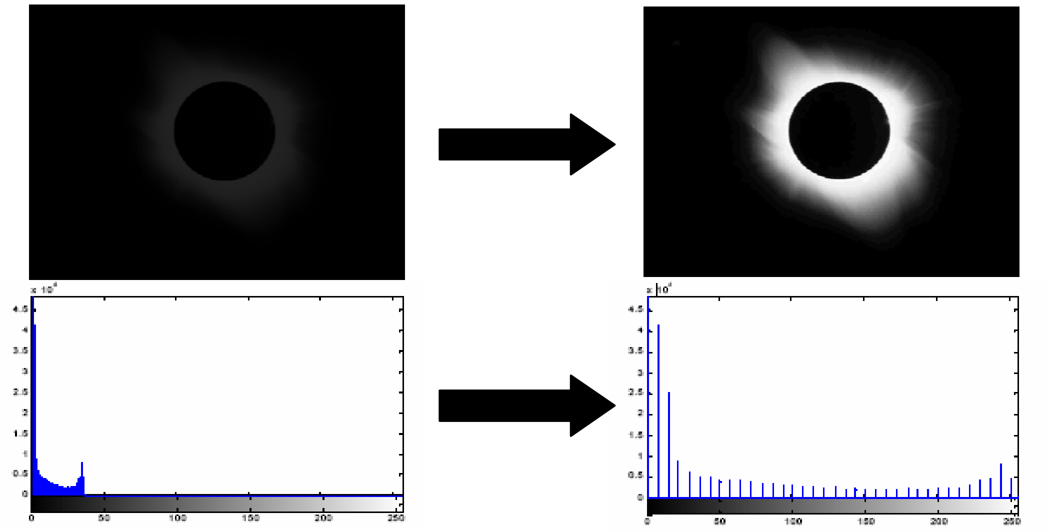


Figure 15 - Brightness Enhancement [4]

3.4.5 Smoothing

Unfortunately, after the subtraction we not only keep the fingers. There is still some noise: many pixels are as bright as the pixels which belong to the fingers. Indeed, with the previous step we also enhance the windows which just contain noise. The solution to correct this problem is to smooth the image. This operation consists in applying a filter on the image.

A filter is a mathematical transformation (called convolution) allowing, for every pixel of the zone (on the input image) to which it is applied, to modify its value according to the values of the neighbour. The filter is represented by a matrix, characterized by its dimensions and its coefficients. His center corresponds to the concerned pixel. The coefficients of the matrix determine the properties of the filter.

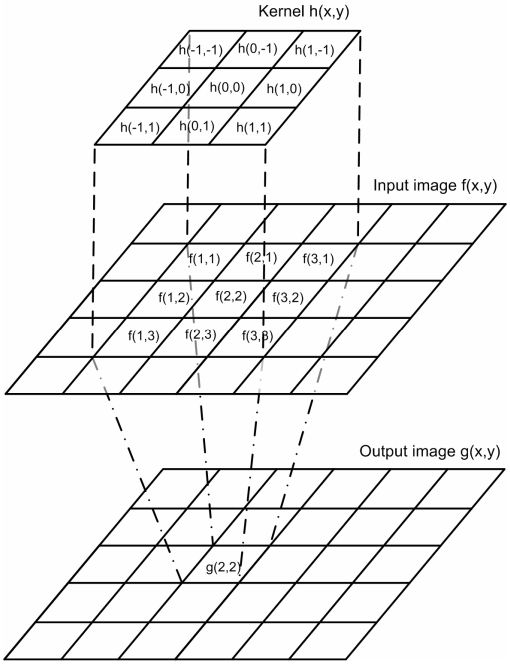


Figure 16 - Filtering operation [5]

In our case, we use a mean filter with the dimensions 5 x 5 pixels. This type of filtering is generally used to damp the noise of the image. The smoothing effect depends strongly on the filter kernel size: the larger the kernel, the larger is the smoothing effect. The principle is to do the average of neighbouring pixels' value. The result of this filter is a more blurry image. The noise will be less bright and the fingers will keep almost the same intensity.

Here is an example of the result that it is possible to get with a mean filter:

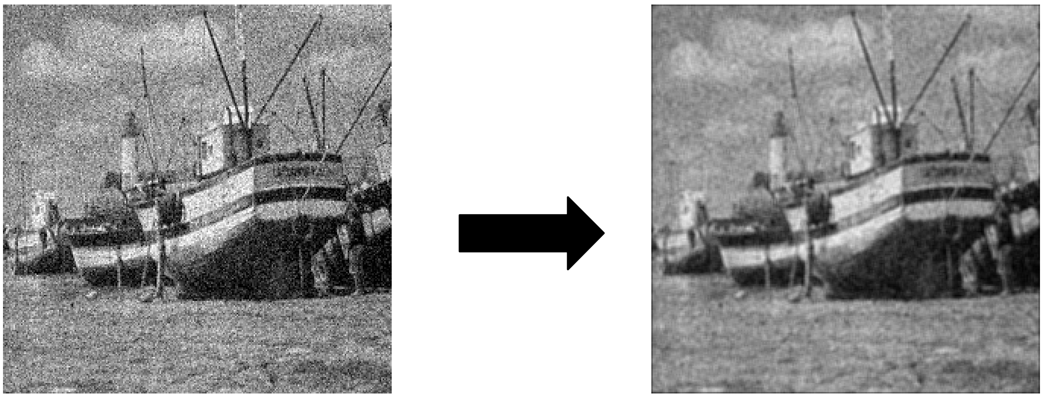


Figure 17 - Smoothing [6]

3.4.6 Binarization

Binarization is an operation which transforms the pixel of an image in two types of pixels: black pixel (value 0) and white pixel (value 255).

Usually, a threshold ε_B is introduced. All the pixels which own a value below the threshold are set in black, while those have a value above the threshold are set in white. Here is the equation which represents this binarization:

$$i_{(x,y)} = \begin{cases} 255 \text{ if } i_{(x,y)} > \varepsilon_B \\ 0 \text{ otherwise} \end{cases}$$

With this operation, we will remove the major part of the noise. On the following page is an example of binarization:

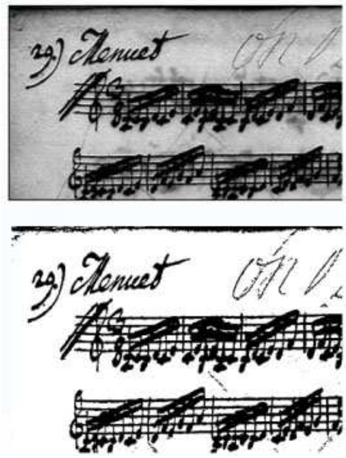


Figure 18 - Binarization [7]

3.4.7 Hole removal

At this moment, the fingers don’t look like continuous areas. It is necessary to transform them into full spaces.

It was decided to take inspiration from the previous projects. The idea was to divide the image in smaller windows (5 x 5 pixels) than in the previous steps. Then, the aim is to check if there are bright pixels which correspond to a finger. To do so, the number of white pixels and black pixels are counted in each window. If there are more white pixels than black, the all window will be set in white. If not, the window will be transformed in a black one.

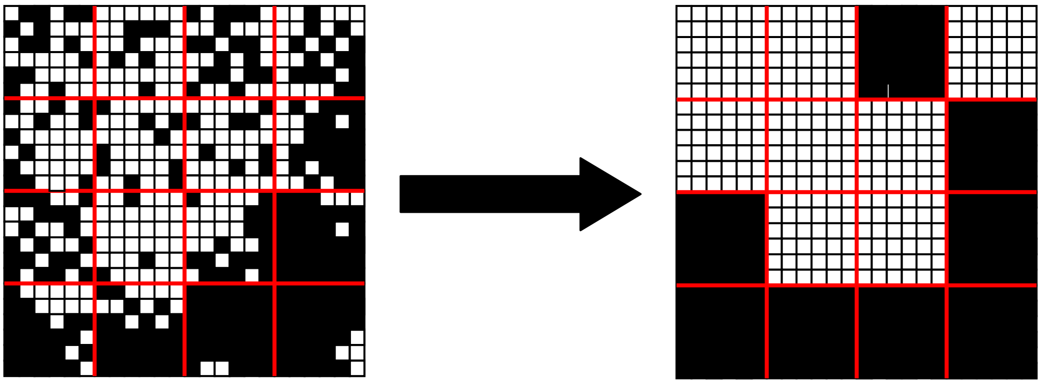


Figure 19 - Holes' removal

Of course, with this method, we keep many windows which just contain noise. This is due to the palm of the hand. But it will be removed thanks to the next step: the size discard. Indeed, the noise is represented by small spots compared to the finger so it is easy to drop them.

3.4.7 Size Discard

Once the fingers are detected, it is necessary to control if they really are fingers. To do so, the size feature is used. Indeed, if the size is too small or too big, the spots won’t be considered as fingers.

The principle is to look horizontally all the pixels in the image starting from the top left corner. When the first white pixel is found, all the neighbouring pixels are checked. If they are similar (i.e. white), they are colored with a uniform colour. Then this method is applied to the neighbours of the first white pixel until the entire area (in our case it is a finger) is detected.

After this, we start again to check horizontally the pixels from the pixel on the right side of the first found white pixel. If the next white pixels belong to the element detected before, their neighbours are not checked.

Each time an element is detected, the number of pixels which constitute this spot are counted. If this number is spread between 15 and 100 pixels, it is considered as a finger and will be kept. Otherwise, it is estimated as noise and will be removed from the image.

After this step, a ROI in form of rectangle is defined around it. The height and the width of this rectangle are calculated and used to find the center of the finger. This method is very accurate because the center of the ROI doesn't correspond exactly to the center of the finger as it is possible to see on the figure 18 (green point: center of the ROI, red point: center of the finger). But it should be enough good to use the application.

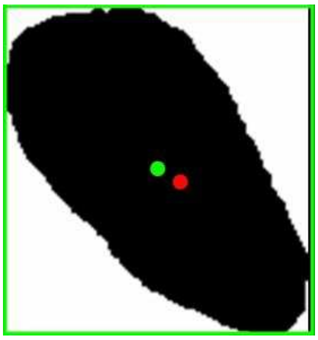


Figure 20 - Center of a finger

3.5 Camera-Projector Calibration

The second feature to get a good processing engine is its precision. It is required to have a right position of the finger. For example, it could be unpleasant to have the red colour to draw while we selected the yellow one.

Unfortunately, the use of a mirror introduces a first distortion. In an ideal case, it could be avoided if the camera and the projector are in the same position (perfectly aligned horizontally and vertically) in a way to have their lens in the middle of the configuration.

Of course, this situation is impossible. That is why it is necessary to make a good calibration between the camera and the projector.

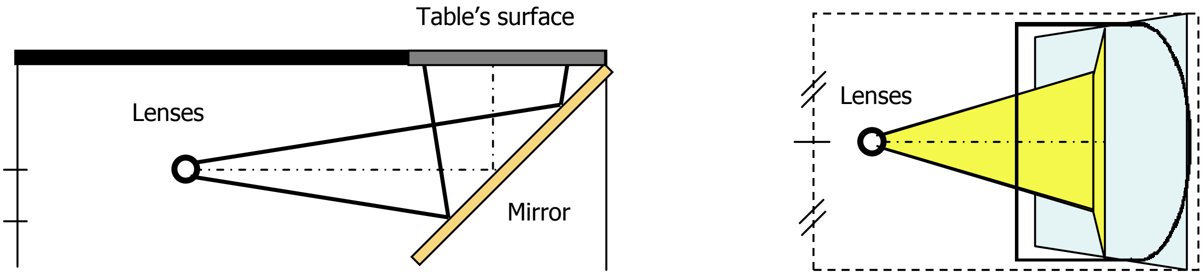


Figure 21 - Ideal setup for the camera and the projector

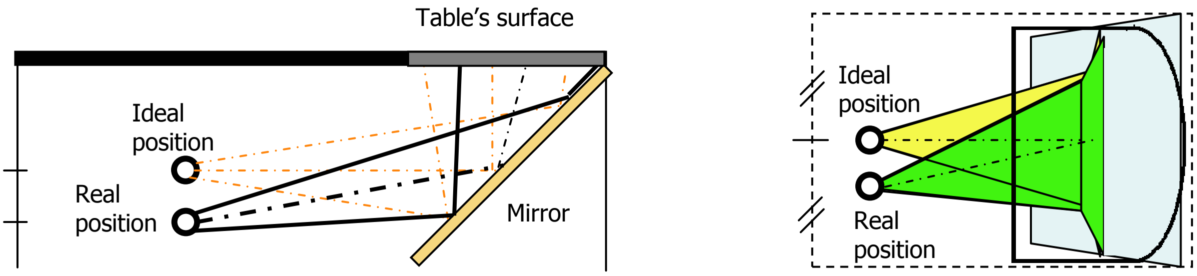


Figure 22 - Real setup for the camera and the projector

The solution for this problem is to find a function which gives to possibility to switch from the camera's system to the projector's system. The aim is to find the coordinates of some points in the two systems and calculate the differences on the horizontal and vertical axis. In the following image, the red points represent the points displayed by the projector and the green ones, those which are seen by the camera.

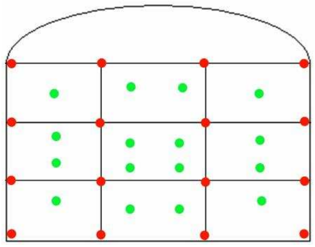


Figure 23 - Grid for the calibration

The differences on the horizontal and vertical axis are calculated in the following manner:

$$x_d(i,j) = (x_{green} - x_{red})$$
$$y_d(i,j) = (y_{green} - y_{red})$$

After this, a linear interpolation is used to get the correlation between all the points of the camera and the projector.

For example, let us consider the first square of the grid. For each point P in this grid, we have to calculate its distortion. The value of the distortion for the points P1, P2, P3, P4 are known from the previous and are respectively the values V_1, V_2, V_3, V_4 (see the figure 22).

Thanks to a linear interpolation it is possible to find the values Va, Vb, Vc, Vd :

$$Va = \frac{(x_2 - a)}{(x_2 - x_1)} V_1 + \frac{(a - x_1)}{(x_2 - x_1)} V_2 ; \qquad Vb = \frac{(x_3 - b)}{(x_3 - x_2)} V_2 + \frac{(b - x_2)}{(x_3 - x_2)} V_3$$

$$Vc = \frac{(x_4 - c)}{(x_4 - x_3)} V_3 + \frac{(c - x_3)}{(x_4 - x_3)} V_4 ; \qquad Vd = \frac{(x_1 - d)}{(x_1 - x_4)} V_4 + \frac{(d - x_4)}{(x_1 - x_4)} V_1$$

Then, to calculate each value Vp, we apply the Goris-Watson algorithm:

$$Vp = \frac{Va.Wa + Vb.Wb + Vc.Wc + Vd.Wd}{Wa + Wb + Wc + Wd}$$

Where

$$Wa = t / (r + 1) ; \qquad Wb = s / (u + 1) ;$$

$$Wc = r / (t + 1) ; \qquad Wd = u / (s + 1)$$

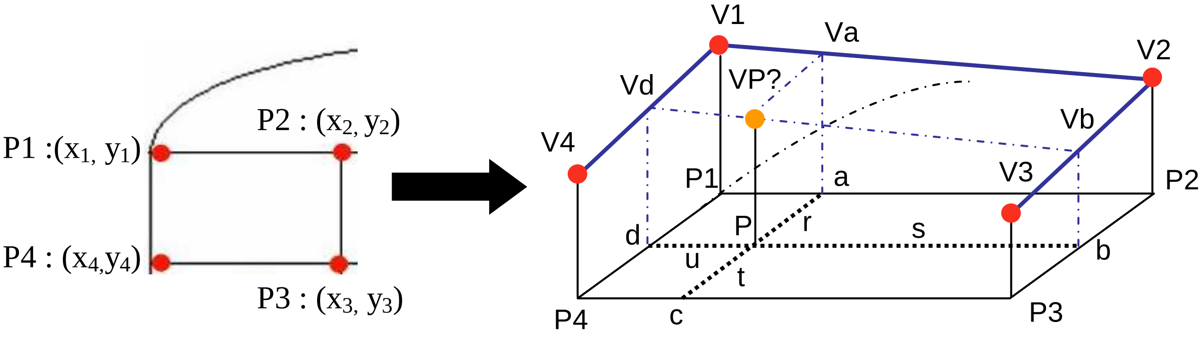


Figure 24 - Interpolation

The second source of distortion is a radial distortion due to the lens of the camera. As it possible to see on the following images, the grid that is displayed on the table's surface thanks to the projector (left figure) won't be perceived in the same way by the camera (right image). This difference becomes more significant as the focal length of the lens decreases [8].

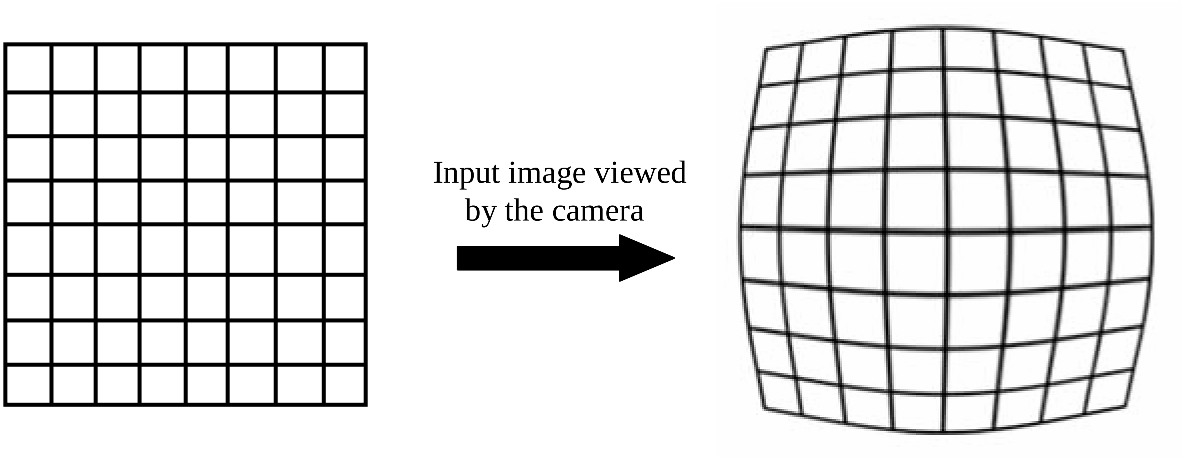


Figure 25 - Radial distortion

This distortion could be also corrected. Here is the formula to overcome this problem:

$$\hat{x} = x_c + L(r)(x - x_c)$$
$$\hat{y} = y_c + L(r)(y - y_c)$$

Where (x, y) are the measured coordinates, $(\hat{x}, \hat{y})$ the corrected coordinates, (x_c, y_c) the centre of radial distortion, $r^2 = (x - x_c)^2 + (y - y_c)^2$ $r^2 = (x - x_c)^2 + (y - y_c)^2$ and $L(r)$ a distortion factor.

3.6 Tracking finger

It is necessary to track the finger in the video stream. Indeed, it is essential to know the distance covered by the finger to draw well the corresponding figure. For example, if the user wants to plot a line and moves his finger from 10 pixels, the result should be a line with a length of 10 pixels.

Here is the algorithm used for this tracking:

```
Check the number of fingers in the current frame
    - If there is at least one finger
        - If there is at least one finger in previous frame
            Calculate the Euclidean distance and update the location of the finger
        - Else create a new finger
    - Else
        - If there is at least one finger in previous frame
            Remove the previous fingers
```

The Euclidean distance *d* between the points A (x_a, y_a) and B (x_b, y_b) is defined in the following way:

$$d = \sqrt{(x_b, y_b)^2} \ d = \sqrt{(x_a - x_b)^2 + (y_a - y_b)^2}$$

Chapter 4

Design

This chapter presents in depth the chosen solutions and their roles. It also describes how they are set up and what are the advantages and the results.

4.1 The light

The first idea was to put the LEDs in series but the drawback is that if one of them is broken, all the circuit doesn’t work.

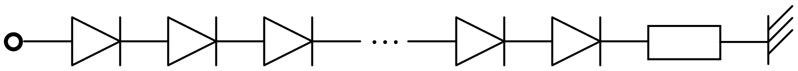


Figure 26 - LEDs in series

Therefore the second solution was to put the LEDs in parallel because with this layout we avoid the previous problem.

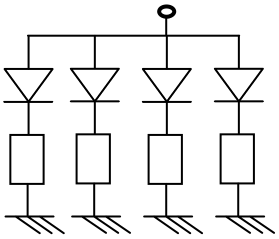
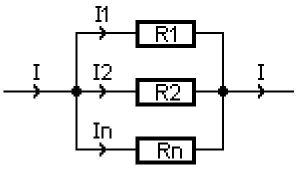


Figure 27 - LEDs in parallel

To know the current used with this solution it is necessary to refer to the Kirchhoff’s circuit law:

“At any point in an electrical circuit that does not represent a capacitor plate, the sum of currents flowing towards that point is equal to the sum of currents flowing away from that point.”



with I =I1+I2+In

Figure 28 - Kichhoff's circuit law

According to the datasheet, each LED needs 100 mA. Then we used a battery of 9V and the used maximal current should be 400 mA. Therefore we could use only four LEDs what is not enough to light the surface of the table.

Therefore the final solution was to mix these two possibilities: to put four lines in parallel and in each line to put five LEDs. This configuration allowed us to have twenty LEDs. Then it was noticed that two circuits of this kind were sufficient to light the entire surface.

To avoid the use of two circuits, we resorted to a generator which allows us to use more current and adjust it.

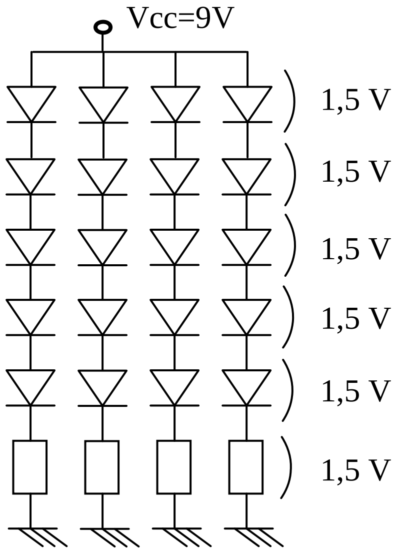


Figure 29 - Final solution

According to the datasheet, the LEDs have an angle of 40°. They are placed on a support so that they are closer to the table' surface and can light the entire surface. The right direction was calculated to light correctly as shows the figure 28.

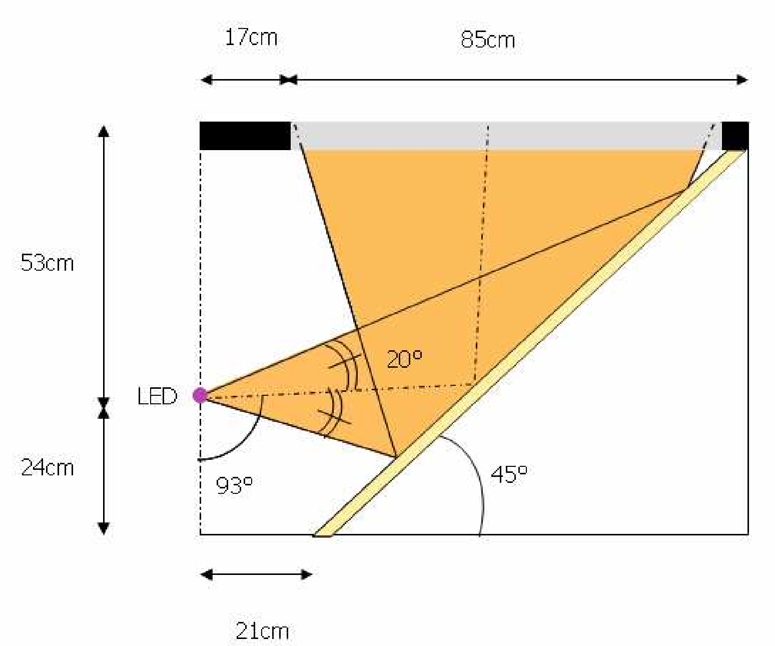


Figure 30 - Position of the LEDs

To angle the LEDs in the right direction we put the LEDs on a piece of wood and we made some holes in it. Then we inserted screws in the holes and adjusted them to obtain the wished angle.

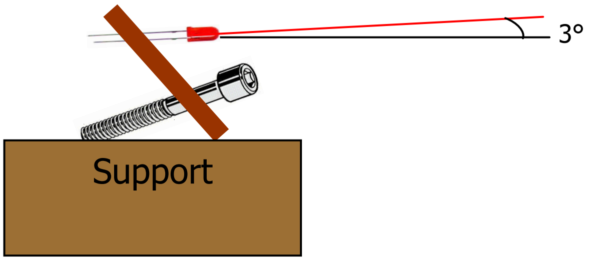


Figure 31 - Orientation of the LEDs

With this configuration, we still have the speculars which arise from the projector and the LEDs. To avoid this problem, it was decided to turn over the glass window of the table. Indeed, this surface is covered by a plastic film which is enough rough to smooth the light from the LEDs and the projector. This solution dims the light but still gives a satisfying result.

4.2 Finger detection

The principle of the multi-touch table is an interaction between the table and the user. To have a good interplay, it is necessary to get an accurate and robust system of finger detection. The aim of this part is to examine the images, to apply them some transformations in order to improve their qualities and extract from them the wished information.

Information about the shape

The table's surface is covered by a white paper and then the sheet is removed. A video of this event is recorded. For each pixel, the minimum and maximal values are searched among all frames.

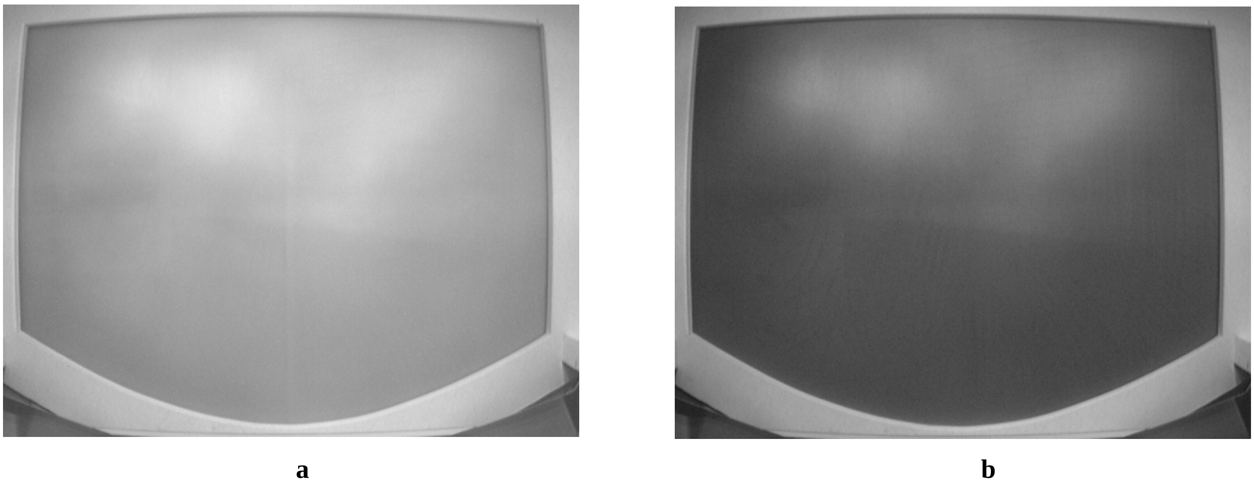


Figure 32 – Image a) with the minimum values b) with the maximum values

After this, the difference between the maximal and the minimum values are calculated and an average image is created.

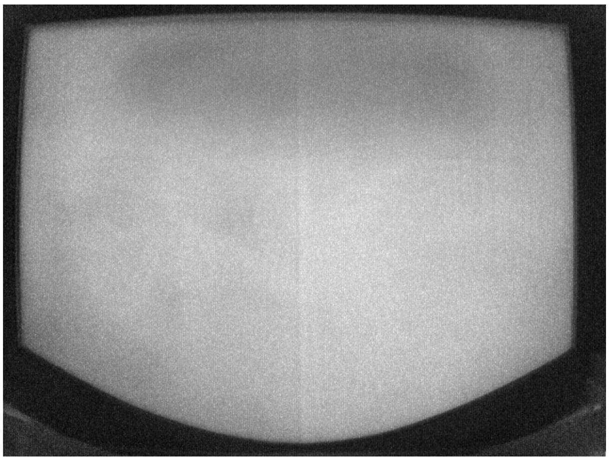


Figure 33 - Average image

There is a bigger difference between the maximal and the minimum value for the transparent surface than for the wood of the table. This involves that on an average image, the wood will appear darker than the transparent surface. So it is easy to apply a threshold to keep only the glass window on the image.

This operation will allow to know where the wood is and to not take into account its pixels during the image processing part. It permits to save some calculations and time.

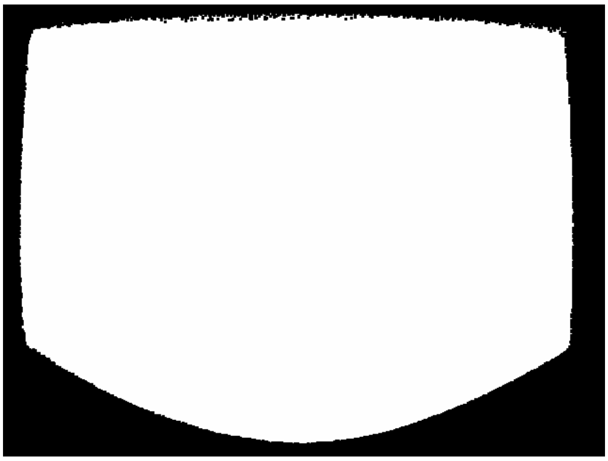


Figure 34 – Final image which shows the contour of the glass window

Image Acquisition

The phase of the image acquisition is essential in a system of vision. His quality will affect simplicity and the robustness of the treatment. A system of vision contains generally:

- a light source
- a sensor (camera)
- an acquisition card (to convert the analogical information from the sensor to a numerical information for the computer)
- a system for the treatment (computer and software)

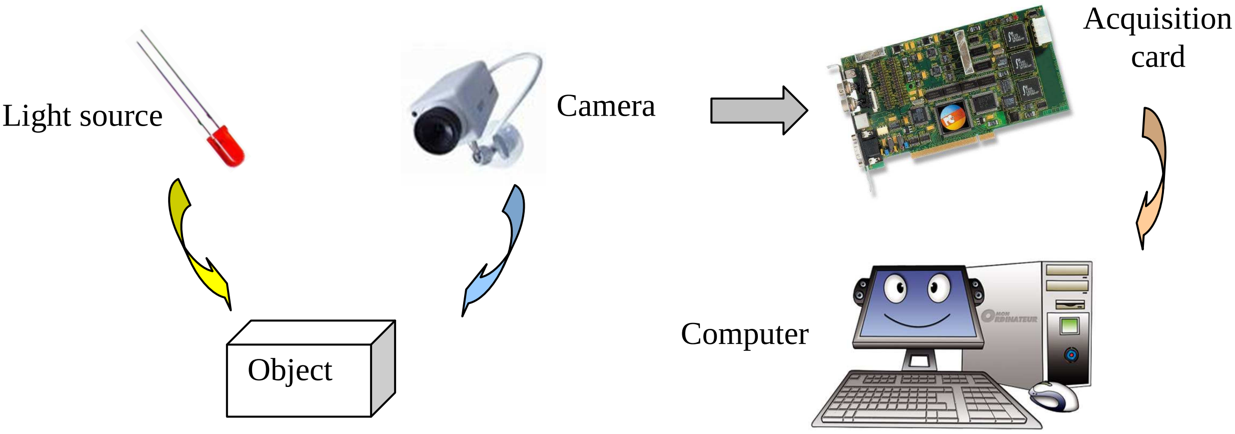


Figure 35 - Image acquisition

In our case, the first acquired image is the background. As explained in the part 3.4.2, the camera needs the first frames to initialize itself. So it is advised to wait few seconds to acquire the good image. Of course during this acquisition, the user is asked to not touch the table because this image will be the reference image and will be used for the subtraction.

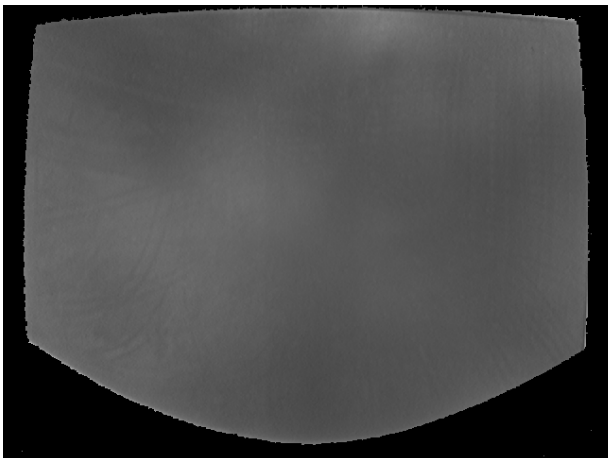


Figure 36 - Reference image

Then, what we call the current frame is recorded.

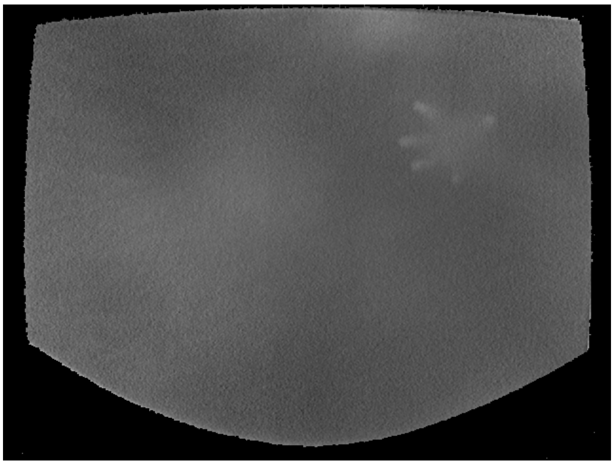


Figure 37 - Current frame with a finger

Subtraction

This stage consists in subtracting the reference image (figure 30) from the current image (figure 29). The outcome of this operation is a black background and the fingers represented by grayscale values.

As is it possible to see on the result (figure 31), there is a lot of noise due to the shadow of the arm and the palm of the hand. Some parts of the noise also arise from the fact that the environment is always changing. The background of the reference image and the current image are not exactly the same. It follows from that some white pixels in the background.

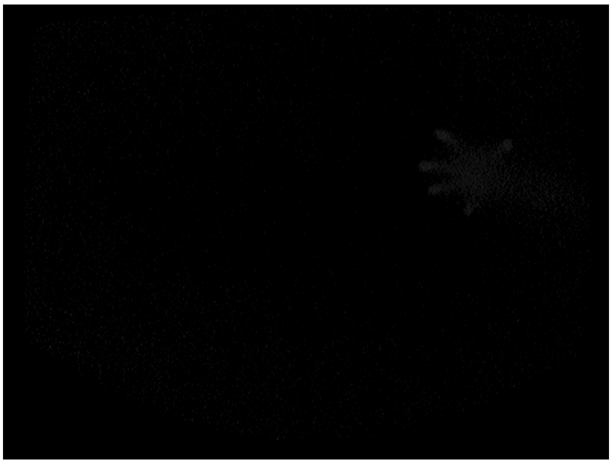


Figure 38 - Subtracted image

Enhancement

The subtracted image is very dark. There is not a lot of contrast between the background and the finger, especially in some areas. Indeed, the light is not homogeneous and some zones are dimmer. The aim of image enhancement is to improve the interpretability of information for human viewers. Here the purpose is to transform the fingers into more bright spots. Unfortunately, this operation also enhances the noise as it is possible to see on the figure 32.

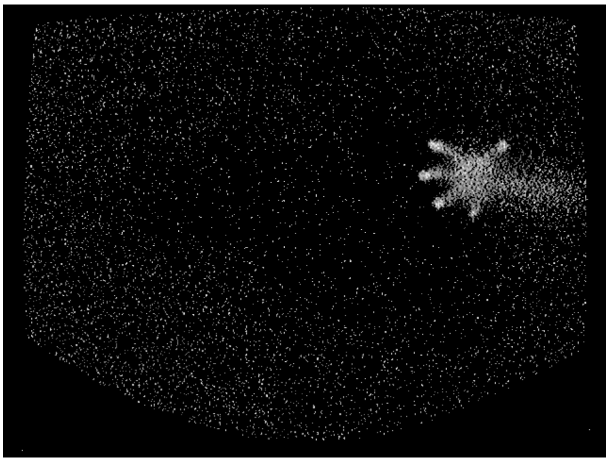


Figure 39 - Enhanced image

Smoothing

If pixels are averaged with their neighbours, the noise which arises from the modification of the environment will be attenuated. Indeed, this noise corresponds to the white separated pixels which means that their neighbours are close to the black.
On the contrary, the finger won’t be too much eased as shows the figure 33.

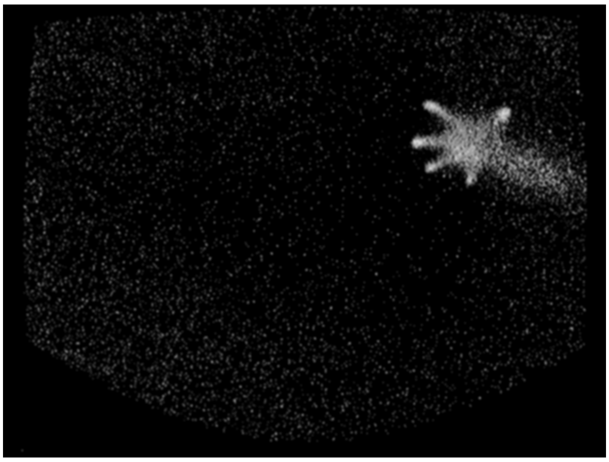


Figure 40 - Smoothed image

Binarization

Once the noise is blurred, a threshold value is introduced to transform the image in a black and white image to remove the noise.

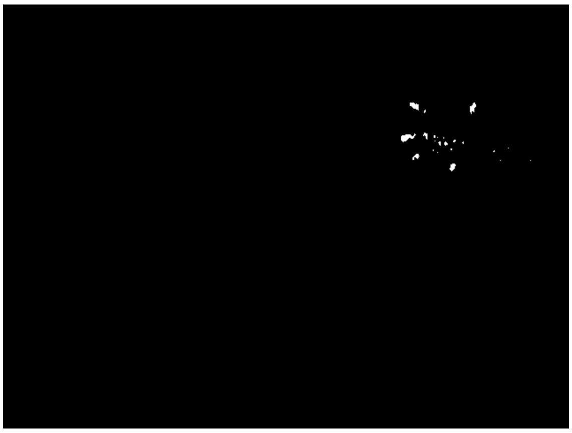


Figure 41 - Binarized image

Holes’removal

It turns out that the manipulation which consists in transforming the finger in continuous areas is not successful. Indeed, it changes the noise in bigger spots and thus it makes the size discard harder. Then, it spins off the shape of the finger (rectangle instead of ellipsis) which distorts the calculation of the finger’s center. And finally, the spots corresponding to the fingers are quite full.

Size discard

The last step is to select the spots according to their size and to calculate their center.

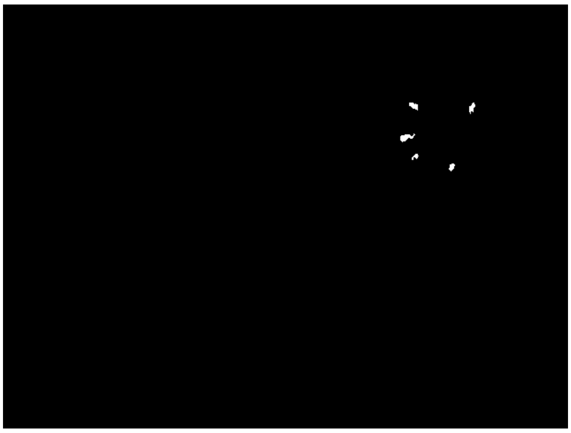


Figure 42 - Size discard

4.3 Calibration

Without correction, there is a big difference (blue lines) between the coordinates from the projector (red spots) and those from the camera (green spots) as it is possible to see on the figure 38.

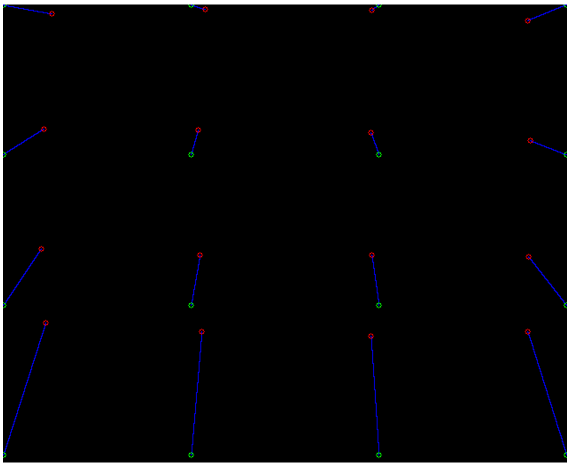
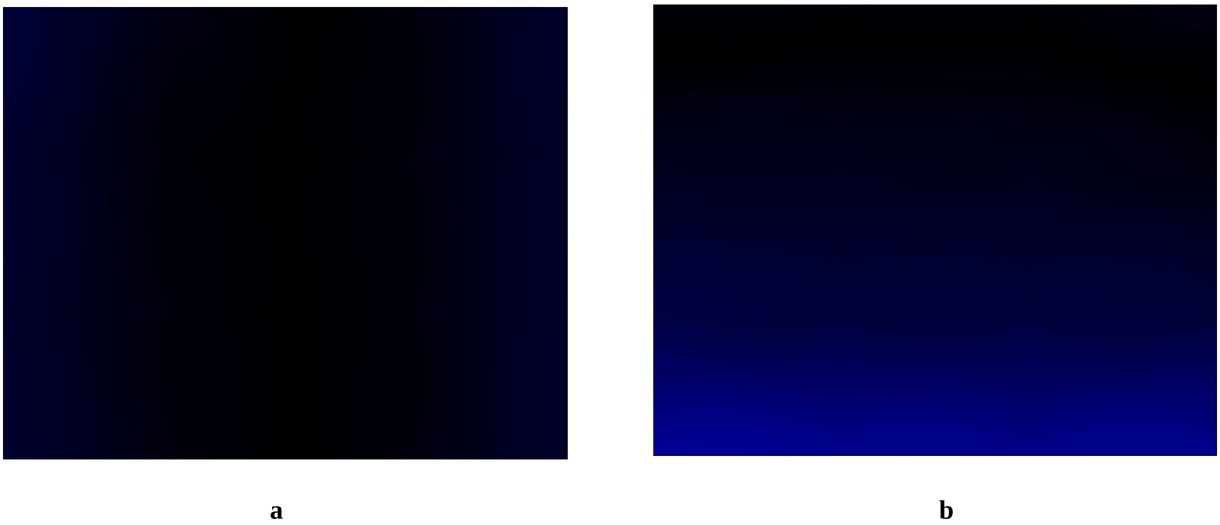


Figure 43 - Distortion

The distortion on the horizontal axis is bigger than on the vertical axis. The following images show these differences: the more it is dark, the less the distortion is significant.



a

b

Figure 44 - Distortion a) on the horizontal axis b) on the vertical axis

After this manipulation, it is possible to switch from the camera's system to the projector's system. Indeed, after the correction of the distortion, if the coordinates of the finger viewed by the camera is displayed on the table's surface, it will correspond to the real coordinates of the finger as shows the figure 45.

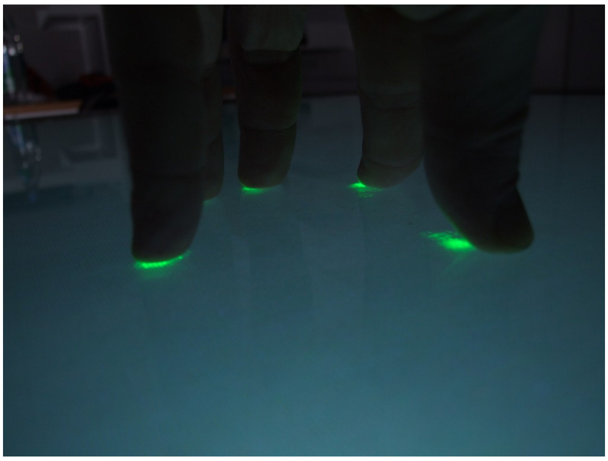


Figure 45 - result of the calibration

This result is enough satisfying. Indeed, the radial distortion can be neglected and won’t be corrected.

4.5 Application

The software “Paint” of Microsoft has proved inspiration to build the interface of the Paint application. This application should be user-friendly and allow the user to draw everything he wants with any utensils. It also should provide the possibility to save the drawing and open an old one.

The main screen owns the same functionalities as the Microsoft software. Indeed, there are a work space where the user can draw, two tools to choose the colours, two accessories to draw and also some buttons which permit to save, open, create a new drawing and close the application.

Despite the brightness enhancement operation provides a more uniform lighting, the borders are still darker than in the middle of the glass. Therefore, the precision to detect the finger is lower on the borders. The interface of the application won’t use the whole surface of the glass window.

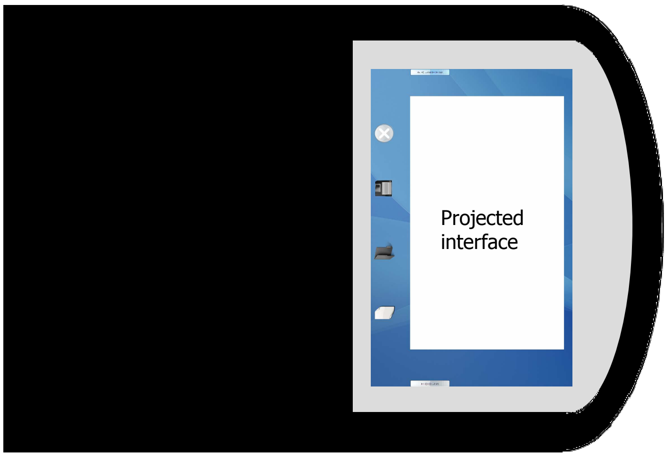
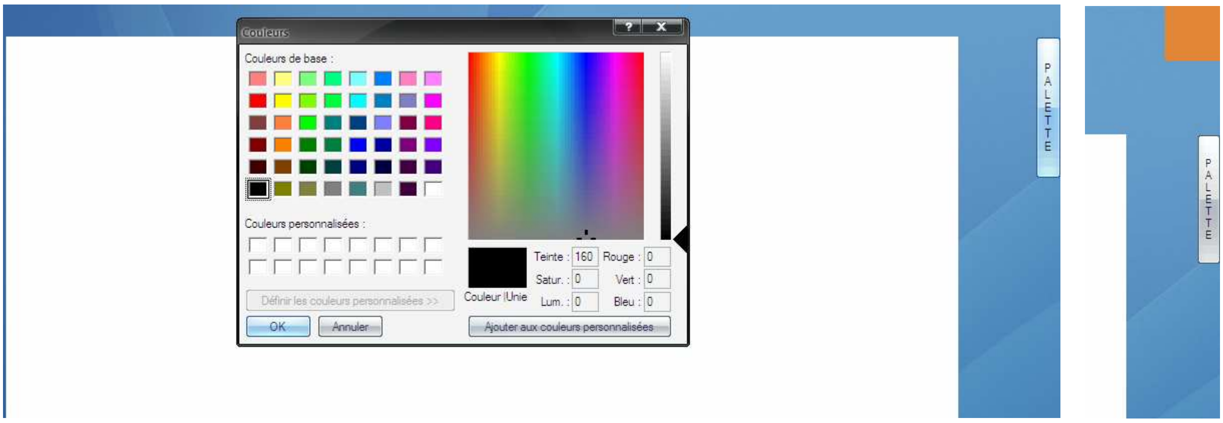


Figure 46 – Position of the projected interface

As said before, the interface contains four kinds of areas. The first one is the work space. This is the white square represented on the figure 45. It is only in this particular space that the user can draw.

Then, two tools are available on each side of the interface. On the right is the colour tool. When the user touches the button “palette”, a pop-up window appears in which it is possible to choose the colour. After the selection, this window disappears and the chosen colour is displayed in the right corner of the interface. This option allows the user to remember easily his choice.


Couleurs
Couleurs de base :
Couleurs personnalisées :
Définir les couleurs personnalisées >>
OK
Annuler
Couleur|Unie
Ajouter aux couleurs personnalisées
PALETTE
PALETTE

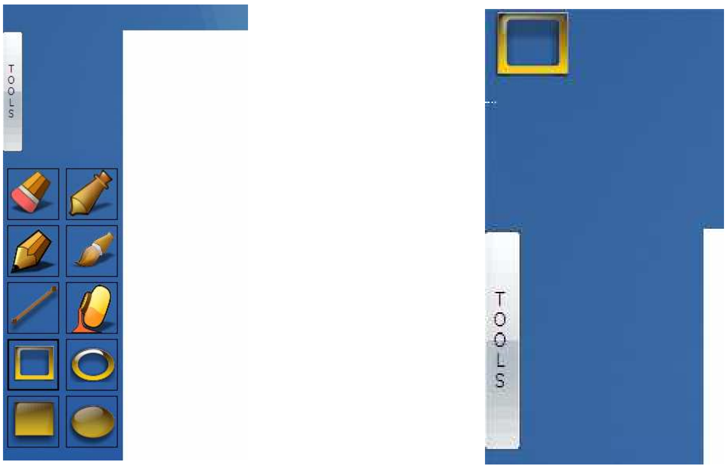
Teinte : 160 Rouge : 0
Satur. : 0 Vert : 0
Lum. : 0 Bleu : 0

a) b)

Figure 47 - Colour tool a) colour selection b) colour display

After the choice of the colour, it is possible to select the utensil in touching the button “tools” on the left side.

At this moment, a range of tools appears on the interface (pencil, brush, rectangle, ellipsis, rubber…). As for the colour, the chosen utensil is displayed on the left corner.



a) b)

Figure 48 - Utensil tool a) utensil selection b) utensil display

The last area contains the basic buttons in the form of icons to create a new drawing which means remove the current drawing, to open an image, to save the current drawing and to close the Paint application. All the images which are saved or opened are in a PNG format.

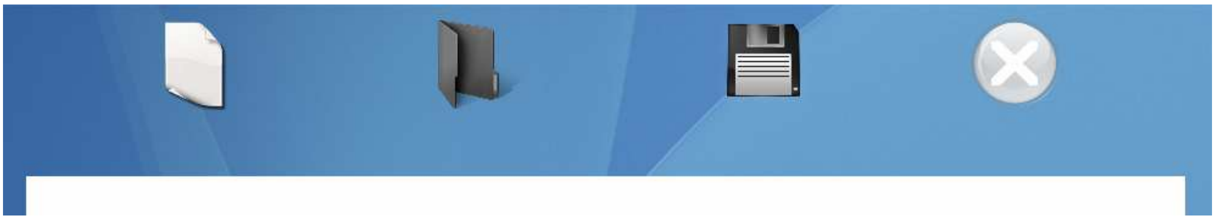


Figure 49 - Icons shapes. From left to right new document, open, save and close application

Chapter 5

Implementation

This chapter explains which implementation is used to create the solutions described in the previous chapter. Firstly, it refers to the physical setup of the table and then to the different languages used to build this project.

5.1 Physical setup

It is necessary to optimize the position of the elements (projector, camera, LEDs …) compared to the table to get a good result concerning the finger detection. For example, as explained in the part 3.5, the setting of the projector and the camera is not ideal which produces a distortion. But it is possible to minimize this distortion if these elements are placed in the best position.

Of course the table and the other objects can be moved. To avoid losing this optimal configuration or spending a lot of time to find it again, all the coordinates of the elements under the table can be measured and marked on the floor. All the details concerning the location of the elements can be seen on the following figures.

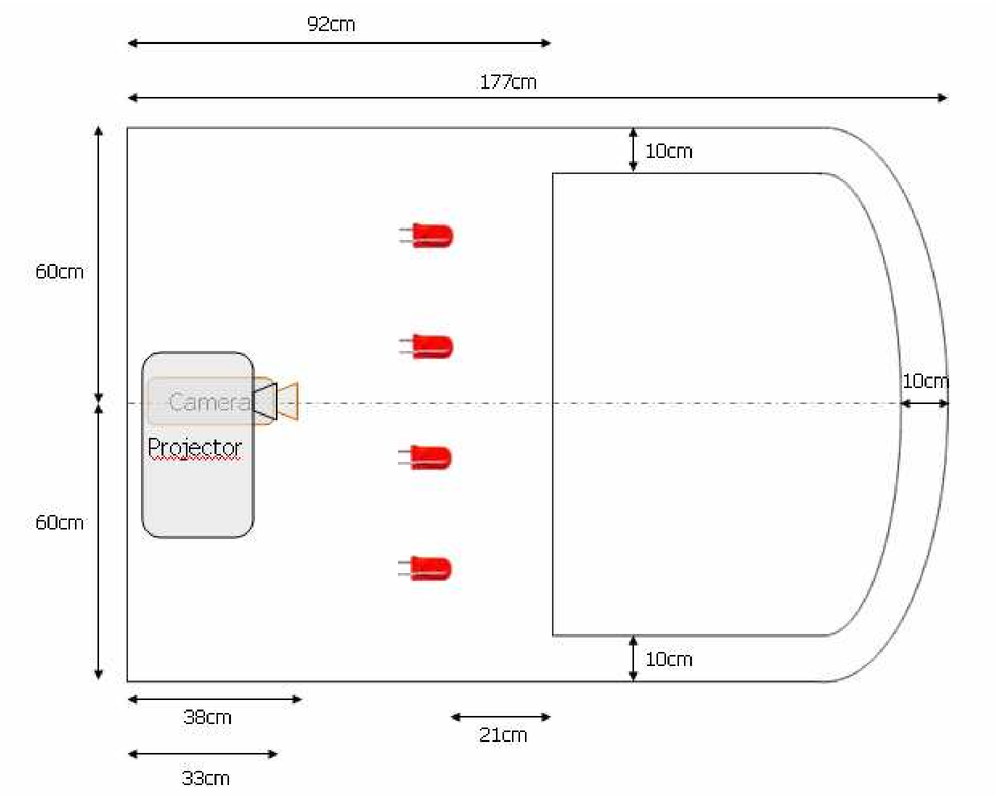


Figure 50 - Position of the elements under the table

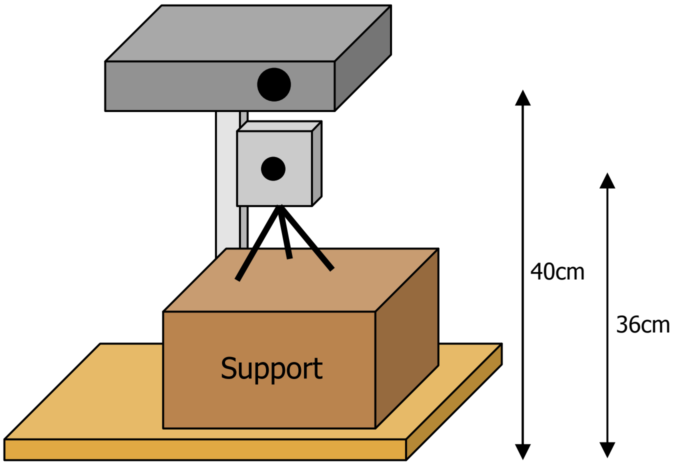


Figure 51 - Position of the camera related to the projector

5.2 Programming choice

As said in the part 2.2.2, the used language to build the finger detection and tracking finger tools is C++. Contrary to the previous projects, the Java language wasn't kept. Indeed, there was a problem of incompatibility between this language and the use of the camera. Then, the language C++ is faster than the Java. This allows the user to have a more efficient image processing part and in particular a good tracking finger.

With it, it is possible to use the library OpenCV (Open Computer Vision Library). This library offers many functions concerning the real-time image processing. Many of them are useful for this project like the ones which permit to use the web cameras (to capture a frame from a video sequence, to get frame information, save a video file…), to apply some filters, to recognize elements… (See appendix A for details)

The choice of the language to make the application is C sharp (C#). The tool used to develop this interface is Visual C# 2005. It allows the creator to put directly some buttons, menus on the interface and the corresponding code is generated automatically. To associate actions, for example on the buttons, with some events, it is necessary to write in the appropriate place made by the creation of the buttons.

Then, Visual C# is integrated to the framework .NET (which permits the interoperability between the different languages) and thus recognizes all the graphical elements of this framework.

Therefore, it is possible to combine it with the image processing part which is written in C++.

The application is a drawing application so it contains many buttons which allow the user to choose the colour and the utensils with which he wants to draw. All the buttons interface were created with the software CorelDRAW X3. It is a vector graphics editor which allows the users to design and edit vector graphics images and save them in many formats. The format used for the project is Portable Network Graphics (PNG).

Chapter 6

Usability tests

Testing is a very important step in the development of a product. It allows the builder to check the viability of his product. The aim is to ask people who don't make the product to use it in order to have an objective opinion and to know the weakness and the assets. In this manner, it is possible to improve the prototype.

The last part of this project is to test its viability. An experience with external people from the work group is done to check if the application works correctly and demonstrates well the efficiency of the multi-touch table technology.

To do so, five people are asked to use this Paint application. The physical setup of the elements under the table, the calibration between the camera and the projector and the calculation of the wood position compared to glass window are made before this test.

The finger detection is not perfect so the use of the application requires some particular conditions. Firstly, the ambient light (from the sun and from the artificial light) should be avoided. That is why the light is turned off and the curtains are closed. Then, if the palm of the hand and the arm are too close from the table’s surface, the noise will appear. The user is asked to place his hand and his arm vertically as much as possible.

Some instructions are given to the user. The execution time of each contestant is written as well as remarks about their use of the application. Then, questions are asked to know their opinion. (See appendix B for instructions and questionnaire)

There were no difficulties for the users to carry out the instructions. They think the functions proposed by the tool are classic. They look like the options offered by the Microsoft Paint. Then, the interface is nice and well design. The functionalities of the buttons are easy to understand.

One drawback is the requirements to use the application. The position of the hand and the arm is restrictive.

The speed and the accuracy of the application are satisfying for the users except for the choice of the colour. The size of the finger is too big compared to the palette. It is difficult to select a precise colour.

Chapter 7

Improvements

After the analysis of the results and the tests, it turns out that many changes can be brought to improve the system. This chapter explains what improvements and development it is possible to do.

7.1 The light

It is possible to improve the light source. Indeed, the actual light is still not homogenous. Then, if it is more powerful, it is probable to obtain better results concerning the finger detection.

One solution could be to use LEDs Single Mounted Device (SMD) tape. In fact, a LED SMD is three LEDs which are included in the same capsule. It allows the constructor to create a smaller system with a better quality. Nowadays, these kinds of LEDs are often used in high resolution systems.

Figure 52 - LED SMD [9]

Then, it could be simpler to have a LED tape. This structure is flexible so it is easier to apply it on the wanted surface. For example, it is suitable for a rounded surface.

Figure 53 - LEDs SMD tape [10]

This permits an equal spacing between LEDs which means a uniform lighting. Then, it could be installed everywhere and according to the wished shape. For example it could be possible to lay it around the window like the Microsoft table.

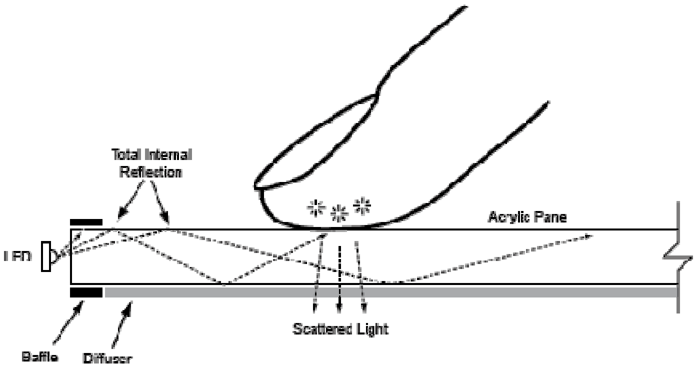


Figure 54 - Configuration of the LEDs [11]

7.2 The use of two camera

The use of two cameras will give the possibility to place them closer to the surface and the mirror. The interest of this manipulation is to obtain at the end a smaller structure. Indeed, for the moment, the table is quite bulky. Such a table (i.e. with such dimensions) could not be commercialised.

The use of two cameras requires an image registration. Indeed, the two images recorded by the cameras will come from different perspective and so won't be in the same coordinates system. The aim will be to put them in the same coordinates system. To do so, the two images will be compared, some similarities (point, contour, intensity…) will be found and some transformations (rotation, translation…) will be applied. Then, the two images will be registered.

Figure 55 - Example of image registration [12]

7.3 Image processing

The finger detection part could be improved. Indeed, the image processing part required many controls for the parameters (value of the thresholds, the size of the spot…) and the system is still sensitive to the noise which is due to the shadow of the palm and the arm as well as the light.

That is why for the good use, it is required to close the curtains, to turn off the light and also to put the arm in a particular position. This imposes too many constraints to the users so the system is not so easy and convivial to use.

Although the parameters were settled in the best way there is still a problem due to the light. As said in the part 6.1 it is possible to improve to light source but it could be possible to improve the finger detection tool itself.

To do so, one solution could be to use some functions proposed by the OpenCV library. Indeed, it offers many possibilities which haven't been explored, due to a lack of time, like object recognition, motion analysis, camera calibration…The use of these functionalities could allow the system to be faster and more accurate, in a nutshell, more efficient.

7.4 Paint application

The current application could be developed. The idea is to create an application like the software Adobe Photoshop which allows a user to retouch and process some images. The application could give the possibility to apply filters to pictures (contour detection, noise removal, colour inversion …) but also to modify the colour's saturation, to binarize, to get a histogram of the image, to make image registration… Other manipulations could be added like the stretching, the reducing, the rotation and the translation of an image.

Chapter 8

Conclusion

This chapter gives the advantages of such a project for a group work and for technical knowledge. It also sums up the state of the project.

This proposed project was very interesting and gave the possibility to learn how to get organized in a group work and to invest in a practical subject. Indeed this project has a real industrial future because nowadays more and more firms try to develop a multi-touch table. Some of them as Microsoft have already commercialised variants of the multi-touch table.

Aside from the human aspect, this project permitted to manage the creation and the installation of many components, to come to grips with a new tool. It also gave the possibilities to apply and expand the computer knowledge.

The objectives concerning this project are achieved. Indeed, the light source was improved and the speculars removed. The finger detection as well as the tracking finger run correctly and give a satisfying result. This allows the application to have an existence. The Paint application is a user-friendly tool which offers a good possibility to draw and save the work.

Of course some evolutions on the tool and the application are still possible as it is possible to see in the part 6 but the final product corresponds to the specifications and it is workable.

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Appendix

Appendix A : OpenCV functions

GUI commands

Create and position a window:

```
cvNamedWindow("win1", CV_WINDOW_AUTOSIZE);
cvMoveWindow("win1", 100, 100); // offset from the UL corner of the screen
```

Close a window:

```
cvDestroyWindow("win1");
```

Resize a window:

```
cvResizeWindow("win1",100,100); // new width/heigh in pixels
```

Video sequence

Initializing capture from a camera:

```
CvCapture* capture = cvCaptureFromCAM(0); // capture from video device #0
```

Initializing capture from a file:

```
CvCapture* capture = cvCaptureFromAVI("infile.avi");
```

Capturing a frame:

```
IplImage* img = 0;
if(!cvGrabFrame(capture))
  {           // capture a frame
    printf("Could not grab a frame\n\7");
  exit(0);
  }
    img=cvRetrieveFrame(capture);        // retrieve the captured frame
```

Releasing the capture source:

```
        cvReleaseCapture(&capture);
```

Get capture device properties:

```
cvQueryFrame(capture);
int frameH    = (int) cvGetCaptureProperty(capture, CV_CAP_PROP_FRAME_HEIGHT);
int frameW    = (int) cvGetCaptureProperty(capture, CV_CAP_PROP_FRAME_WIDTH);
int fps       = (int) cvGetCaptureProperty(capture, CV_CAP_PROP_FPS);
int numFrames = (int) cvGetCaptureProperty(capture,  CV_CAP_PROP_FRAME_COUNT);
```

Get frame information:

```
float posMsec   =       cvGetCaptureProperty(capture, CV_CAP_PROP_POS_MSEC);
int posFrames   = (int) cvGetCaptureProperty(capture, CV_CAP_PROP_POS_FRAMES);
float posRatio  =       cvGetCaptureProperty(capture, CV_CAP_PROP_POS_AVI_RATIO);
```

Set the index of the first frame to capture:

```
// start capturing from a relative position of 0.9 of a video file
cvSetCaptureProperty(capture, CV_CAP_PROP_POS_AVI_RATIO, (double)0.9);
```

Image processing

To fill the connected domain, start from seed pixel while the pixel values in this domain are not far from each other:

```
cvFloodFill( CvArr* array, CvPoint seedPoint,
                         double newVal, double loDiff, double upDiff,
                         CvConnectedComp* comp, int connectivity CV_DEFAULT(4) );
```

To define a rectangle:

```
cvRect(int x,int y, int width, int height);
```

Appendix B : Usability test

Instructions

Draw an empty blue ellipsis
Rub off the drawing and draw a green line and a full red rectangle
Save the drawing
Open a file and draw on it
Close the application

Questionnaire

<u>Personal questions</u> :

How old are you ?
What is your job ?
Are you □ a female □ a male ?

<u>Questions about the product</u>:

Are the requirements restrictive :
□ Strongly disagree □ Disagree □ Neutral □ Agree □ Strongly agree

Easy to do the instructions:
□ Strongly disagree □ Disagree □ Neutral □ Agree □ Strongly agree

Are the functions pertinent:
□ Strongly disagree □ Disagree □ Neutral □ Agree □ Strongly agree
Good design:

□ Strongly disagree □ Disagree □ Neutral □ Agree □ Strongly agree

Is the table efficient:
□ Strongly disagree □ Disagree □ Neutral □ Agree □ Strongly agree

<u>Any comments</u> :