Technical report

Report on the extension of iDesk

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Introduction

This report describes the design, implementation and evaluations of the document detection and pointing recognition in the iDesk application. Research on pointing devices has already been done in great extent [refs] however most of them are only usable in a controlled static environment. Dynamic lighting which occurs in any normal environment troubles the accuracy and performance in most of the papers. For the iDesk the need for a robust pointing detection was of great importance. From various possible methods the following are selected: background subtraction, skin color detection and for matching the actual hand fast normalized cross correlation is used. Also a method for detecting and rectification of documents is developed. This method makes use of the Hough transform on the subtracted foreground gradients. Iterating over the detected lines detects documents structures, which are rectangles. The pinhole model and a projection matrix are used to rectify captured documents. All the separate parts are evaluated whether they are applicable to the presented problem.

Also an interaction is designed to select a point in a document. To test the usability of the interaction a number of tests are done. During these tests the usability of the iDesk system was also measured.

This report also includes the implementation, a compilation manual and a user manual.

1.Problem definition

Introduction

The Image Understanding and Pattern Recognition group (IUPR) of the DFKI has developed an interactive desktop environment called the iDesk demonstrator. The iDesk demonstrator is designed to be a real desk in order to show how to bridge the gap from the offline to the online desktop. A standard digital photo camera is mounted on top of the iDesk to observe the user's desktop. The low-resolution image of the viewfinder is processed in real-time to detect documents in the field of view. As soon as a document is detected, a high-resolution image is acquired and the document image is extracted. The product is designed for a large group of users (from administrative staff to researchers and consumers). Also the overall cost of the product should be low, therefore it is preferred that one should be able to create the product from consumer products. It is important that the system can be used in different settings under different conditions (eg. lighting).

Document detection

The current method of document detection is not reliable enough. The possible methods to detect and rectify the document are to be explored.

User interaction

A more natural user interaction is desired, the first step is providing the possibility for users to point in documents. Therefore the hand must be segmented and the fingertip must be located. The various methods available to detect the hand and fingertip are to be explored.

Deliverables

A working prototype is to be implemented and tested. An application called CamCap is already available, which is to be extended with the functionality described above.

2.Requirements

In this chapter the main requirements of the system are described. The system should comply with all the given requirements given below. The requirements are subdivided into functional and non-functional requirements.

Functional requirements

These section defines the functional requirements. The requirements are split up in several subsections.

1. Input

The user can interact with the system by putting documents in the viewfinder image and providing pointing gestures to the system.

1.	Document	Documents placed in the viewfinder of the camera should be detected.
2.	Document	All detected documents should be captured.
3.	Document	Multiple detected documents on the desk at once should all be captured.
4.	Pointing	Hands in the viewfinder image should be recognized.
5.	Pointing	The position of the fingertip should be detected.
6.	Pointing	A pointing action should be detected.

2. Output

After the user has provided some input to the system there should be some output to the user. The next section describes the requirements of this ouput.

2.	Feedback	When a document is detected this should be corresponded with the user using audio-visual feedback.
3.	Feedback	The user should be informed of a detected fingertip using audio-visual feedback.
4.	Feedback	When a pointing action is detected the user should be informed using audio-visual feedback.
5.	Document	The captured document should be rectified, eliminating transformations caused by the perspective view.
6.	Document	There should be a minimum of edges around the rectified document (1 or 2 pixels).
7.	Document	The rectified documents should be displayed in the captured-documents-browser.

3. Storage

The system has to store some data so it can be used later by others programs or for further processing by the system.

3.	Document	Each rectified document should be saved as an image (png) file.
4.	Document	Pointing locations found in documents should be saved in a data file.

4. Computation

Computation of the system should be done in near real-time. Minimal framerate of the application should be 2 to 3 frames a second.

Non-Functional requirements

5. Response time

The system should response in real-time to input provided by the user. Document rectification however is done in the background and should complete in a timely manner.

6. Throughput

The throughput of the camera should be realtime so delay is kept to a minimum.

7. Resource usage

Document detection, rectification and finger tracking require a huge amount of resources. The program however should be able to run real-time on an average consumer personal computer. Also it must be possible to create the system with consumer products.

8. Reliability

The system should not crash unexpectedly due to uncaught exceptions. Memory leaks or invalid memory access should not occur.

9. Allowance

The system should be programmed and documented in such a way that allows future additions to the program.

10.Platform

Linux.

11.Technology to be used

- Canon A620 or Canon S50 digital camera
- Personal computer with an USB port, running Linux with wxwidgets libraries and

usb-tools installed.

- All technology used should consist of consumer products.

12.Development

The system has to be developed on the last stable version of the CamCap application. The program should improve on document detection and rectification precision. It should also contain finger tracking and must be compilable on both unicode and non-unicode systems.

13.Date of delivery

The system should be delivered on the 16th of February 2007.

3.Problem analysis

Environment

The prototype should work in different environments under different conditions. The main influence in different environments is lighting. Different lighting conditions influence the images that are acquired from the camera. These vary from natural lighting to various artificial light sources. The system should be able to adapt to changes in lighting as well. For example sunlight is blocked for a short period should not change the performance of the system. This requires either an adaptation of the system to the change in lighting or a method that is independent of these lighting changes.

The system should work on different desks and with different cameras. The chosen methods need to be very flexible and independent of properties of both the desk and the camera. Therefore it is important that no static data about the environment is used by the system. It is very likely that desks which have a light color have a low contrast with documents which are most likely white. It is to be researched whether there are methods available or that can be developed which solve this problem. Also skin color-like desks can be a problem when skin segmentation is used.

Users

Everybody who uses a computer and has to deal with documents is considered as a possible user for this system. Therefore we aim at experienced computer users. The only requirement is that they have a desk, a camera, and a computer. This means that the target user group is very large. The most important factor is different hand sizes and skin colors. Since this is the only input that is not mouse and keyboard.

Current system

iDesk

The current iDesk consists of a wooden desk with a Canon A-260 camera mounted on top. The camera is directed down to provide a top down view of the desk. A difficulty is that the brown color of the desk is very skin color like. Skin color detection is very useful for hand segmentation, if this is to be used a suitable solution needs to be found for this problem.

Camcap

Camcap is an application which is developed at the IUPR research group. Camcap can acquire images from the viewfinder of several camera's. It also can load images from disk, this is mainly used for testing purposes. From the user's view Camcap has three states:

- Stopped, the camera is turned off.
- Running, images from the viewfinder are captured and document detecion is enabled.
- Paused, images from the viewfinder are captured. Document detection is turned off.

Camcap provides the following functionality:

- Background resetting: Resets the background, the next image is taken as the new background.
- Contour drawing: Draws a contour around the detected documents.
- Cluster drawing: Draws circles on the cornerpoints of detected documents.
- Zooming: Zooms in/out, this requires that a camera is used for providing the images.
- Captured documents viewer: Shows the captured documents, these are rectified by the application.
- Debug information: Allows users to select the log level, which indicates which messages are displayed. Also the user can choose to output the log information to a file or the console.

Known problems

Whenever the camera (Canon A260) is turned on and there is no document in the viewfinder the colors in the images that are acquired from the camera have a very distorted color spectrum. The images appear to have high values of blue. Putting in a document or another white object resolves this problem. Since the gesture recognition is only used in combination with document detection this will not be dealt with.

What does form a problem is the radical changes in the colors whenever a new object is put in or removed from the viewfinder. The R B and G values can change about 15% each.

4.Previous work

Many possible methods have been researched and developed in the field of gesture recognition. In this chapter we will focus on hand and finger detection. There is a wide range of possibilities when one wants to detect hands and fingertips. In almost all cases first an attempt is made to segment the hand and then detect the fingertip. In most cases these methods are tested in controlled environments. This means constant lighting and static backgrounds are used. In a different setting these methods tend to fail. For example if there is an object in the background with a high skin color likelihood using only skin color detection will not be sufficient.

Hand detection

The simplest method is to make use of an infra red camera as in [OKA03] and [WIL05]. The human body has a constant temperature and the hands can be detected by thresholding between 30 and 34 degrees Celsius. This method is very robust because it is independent of dynamic lighting and changing backgrounds. But this does require the use of an infra red camera.

A very popular method is background subtraction (for example, see [ZHA01] [HAR01] [NOK98]). There are various methods available to subtract the background from a scene. A basic method is to take the first N frames of a sequence and calculate the average value of each pixel, then each next frame is thresholded with the background. Whatever is not deleted becomes foreground. More complicated methods use algorithms to update the background continuously. For an review of different background subtraction techniques see [PIC04].

Another popular and commenly used method is skin color detection [WU02] [WAC05] . Skin color detection uses information about human skin color which has very specific characteristics. Using this information hands can be segmented from any other object in the scene. Also for this method there are various approaches. [VEZ03] provides an overview of available skin color detection methods. The disadvantage of using skin color detection is that either a model or a classifier need to be trained, this requires lots of skin and non-skin colored data.

Other less commenly used methods are:

- Motion detection [CUI97].
- Line matching [ATH03].
- Adaboost [KOL04].
- Blob and ridge searching [LAP01].

Fingertip detection

After the hand has been segmented the exact location of the fingertip (of the index finger). Again there is more than one approach that can be applied. Matching seems to be a logical solution to this problem and is often used. For example [CRO95] uses SSD with a template to calculate the most probable location of the fingertip. There are various matching algorithms available, the most important difference is the complexity of these algorithms.

Also different classification methods are used for finding a fingertip location such as neural nets [NOL98] to detect features that are extracted through some preprocessing method. The advantage of feature detection is that it tends to be very accurate, also in some methods the hand detection can be skipped. But often these methods are slow, barely reaching one or two frames per second on a workstation.

Whenever a hand is found another possibilty is to fill the hand and try to detect the fingers (see [HAR01] or [MOE04]). Using the knowledge that the width finger is only a couple of pixels depending on the distance of the camera fingers can be detected when the hand is floodfilled.

Document detection

Detection of documents or other quadrangles in images has already been done in [WUY00],[ZHA03] and [ZHA03b]. First the gradients in the images are detected, after which lines are searched in those gradients using Hough transform. In [ZHA03] a quadrangle is found if four lines match the following conditions:

- Opposite lines should have quite opposite orientations (180° within 30°)
- Opposite lines should be quite far from each other (bigger than one fifth of the image height or width)
- Angle between neighboring lines should be close to 90° (within 30°)
- Orientation of the lines should be consistent (either clockwise or counter-clockwise)
- Quadrangle should be big enough (circumference should be larger than (W+H)/4)

The difference in the implementations in the mentioned papers is that only a single quadrangle is found, whereas in the CamCap application it should be possible to have multiple documents in the viewfinder image.

Document rectification

The papers used for document detection also address the problem of perspective transformation of the input image. In all three papers the images are rectified using the pinhole model [FAU93]. In [ZHA03] an elaborate explanation is given how to intrinsic matrix, rotation matrix and translation vector are calculated. In the CamCap application the solution for detecting the focal point and determining the aspect ratio is used from these papers.

Rectification however is by determining the projection matrix using common 3D computer vision techniques described in [HOR86]. This is done because of an unknown scaling factor the first three papers.

5.Design

Introduction

This chapter describes the used methods to create a robust and flexible system. To design such a system a number of methods will be combined. As described in Chapter 4 there are various methods that can be used for detecting hands and fingers. Most methods used in previous work are not robust, they are either unable to adapt to changes in lighting or in changing background (for example an new inserted object in the scene). But a combination of these methods will enable us to create a system that is independent of it's environment and does not perform less when the environment changes.

Background detection

Having the requiments in mind background subtraction seems to be a proper solution. Using this technique we can both segment the documents and the hand from the rest of the scene. To avoid that new objects in the scene and dynamic lighting will not distupt the system we can consider a number of strategies (for details and comparison see [PIC04]):

- Kernel density estimation
- Mixture of Gaussians
- Sequential density approximation
- Temporal median filter

Taking speed and accuracy in lesser importance memery usage into account a mixture of Gaussians is the best choice for robust background subtraction. This method is described in [STA99] and is used for real-time tracking, in the paper it is used for tracking traffic. The method models each pixel as a mixture of Gaussians. A pixel is defined in the RGB color space, therefore pixel $X=\{R,G,B\}$. The history of pixel $\{X_{1,..},X_t\}$ is modeled by K Gaussian distributions. The probability of observing pixel X_t is:

$$P(X_t)=\sum_{i=1}^{K}\omega_{i,t}*\eta(X_t,\mu_{i,t},\Sigma_{i,t})$$

where K is the number of Gaussian distributions, $\omega_{i,t}$ is the weight of the i-th distribution at time t, $\mu_{i,t}$ is the mean of the i-th distribution at time t, $\Sigma_{i,t}$ is the covariance matrix of the i-th distribution at time t and η is the Gaussian probability density function:

$$\eta(X_t,\mu,\Sigma)=\frac{1}{(2\pi)^{\frac{n}{2}}|\Sigma|^{\frac{1}{2}}}e^{-\frac{1}{2}(X_t-\mu_t)^T\Sigma^{-1}(X_t-\mu_t)}$$

The avoid matrix inversion the covariance matrix is simplified to the form:

$$\Sigma_{k,t}=\sigma^2 I$$

The K Gaussian distributions are sorted according to their weights in descending order. We used the first N of K Gaussian to define background, which is suggested in [STA00]. This means that the N Gaussian with the highest weights are considered background. Whenever a new pixel is presented to the model the model is updated as follows:

1. Iterate through the K Gaussians.
2. Whenever the pixel value is within 2σ of a distribution that distribution is updated according to the update functions.
3. Update weights of all distributions

Whenever is not considered to be part of any of the K distributions a the distribution with the lowest weight (i.e. the K-th distribution) is replaced by a new distribution with $\mu_{k,t}=X_{k,t}$ and a low $\sigma_{k,t}$ and $\omega k,t$.

The weights are updated as follows:

$$\omega_{k,t}=(1-\alpha)\omega_{k,t-1}+\alpha(M_{k,t})$$

where α is the learning rate and $M_{k,t}$ is 1 for the distribution that matched X_t and 0 for the other distributions.

The update functions are modeled according to K-means, this is a good estimation of the new values of the distributions without having to use a window of recent pixels. The update functions are as follows:

$$\mu_t=(1-\rho)\mu_{t-1}+\rho X_t$$

$$\sigma^2=(1-\rho)\sigma^2{}_{t-1}+\rho(X_t-\mu_t)^T(X_t-\mu_t)$$

where ρ is the second learning rate:

$$\rho=\alpha\eta(X_t|\mu_k,\sigma_k)$$

The advantage of using the mixture of Gaussians is that objects that are new in the scene can quickly be merged with the background and changes in light intensity can quickly be resolved depending on the value of α . One disadvantage is that whenever a hand or a document is at the same position long enough it will dissolve in the background. To avoid this problem we allowed to add masks to the background model. In the mask a value of 0 indicates that the corresponding pixel is to be processed and a 1 indicates that the pixel is not to be processed. This does require fast detection of hands and documents because otherwise they will be dissolved before they are detected.

Shadow detection

One aspect that the chosen background model does not take into account is shadow. As will be described in Chapter 7 drop shadows are a problem for proper hand detection. Whenever a user points the arm and hand create a drop shadow. To eliminate this problem we modeled shadow and excluded detected shadow from the foreground. Detected shadows are not included in the mask. From experiments was learned that excluding shadow from the background performed worse than including shadows.

We use a method similar to the one presented in [KAE01], each new pixel which is presented to the background model is first checked to the current background Gaussians. If the pixel is considered as shadow of one of the foreground Gaussians (i.e. the N first Gaussian) the pixel is labeled as shadow it is only removed from the foreground and still fed to the background detection. The method used for detecting shadows is described in [HOR99].

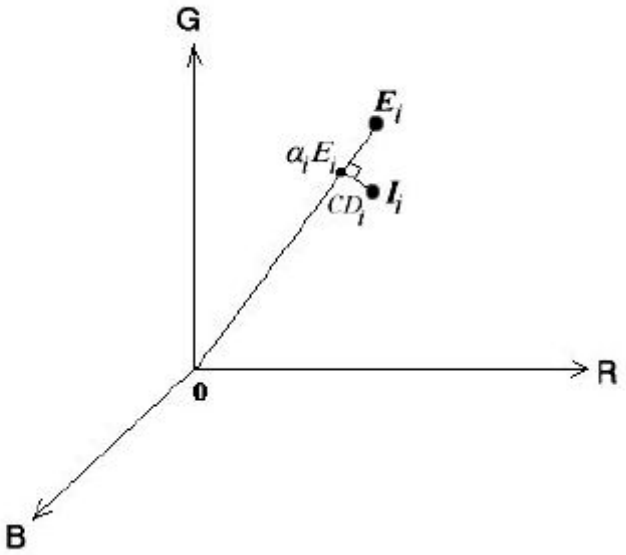


Figure 1: Model for detecting shadow proposed by Horprasert et al.

Figure 1 illustrates the method proposed by Horpasert et al. The background pixel $\boldsymbol{E_i}$ in the RGB color space. The line $0\boldsymbol{E_i}$ is the expected chromaticity line, each pixel on this line is considered to have similar chromaticity and therefore is shadow. For a new pixel, say $\boldsymbol{I_i}$, the chromaticity distance CD_i (the orthogonal distance between the chromaticity line and the color value of pixel $\boldsymbol{I_i}$) and the brightness distortion α_i (the strength in brightness of pixel $\boldsymbol{I_i}$ with respect to $\boldsymbol{E_i}$).

α_i and CD_i can be calculated as follows:

$$\alpha_i = \frac{\left(\frac{I_{r,i}\mu_{r,i}}{\sigma_{r,i}^{\ 2}} + \frac{I_{g,i}\mu_{g,i}}{\sigma_{g,i}^{\ 2}} + \frac{I_{b,i}\mu_{b,i}}{\sigma_{b,i}^{\ 2}} \right)}{\left(\left[\frac{\mu_{r,i}}{\sigma_{r,i}} \right]^2 + \left[\frac{\mu_{g,i}}{\sigma_{g,i}} \right]^2 + \left[\frac{\mu_{b,i}}{\sigma_{b,i}} \right]^2 \right)}$$

$$CD_i=\sqrt{\left(\frac{I_{r,i}-\alpha_i\mu_{r,i}}{\sigma_{r,i}}\right)^2\left(\frac{I_{g,i}-\alpha_i\mu_{g,i}}{\sigma_{g,i}}\right)^2\left(\frac{I_{b,i}-\alpha_i\mu_{b,i}}{\sigma_{b,i}}\right)^2}$$

where $I_{r,i}I_{g,i}I_{b,i}$ are the R,G and B values of pixel I_i respectively, $\mu_{r,i},\mu_{g,i},\mu_{b,i}$ are the means of the R,B and B values respectively, $\sigma_{r,i},\sigma_{g,i},\sigma_{b,i}$ are the standard deviations of pixel I_i respectively.

To reduce the number of operations that need to be performed at run-time α_i can be computed according to some precomputed values:

$$A_i=\left(\left[\frac{\mu_{r,i}}{\sigma_{r,i}}\right]^2+\left[\frac{\mu_{g,i}}{\sigma_{g,i}}\right]^2+\left[\frac{\mu_{b,i}}{\sigma_{b,i}}\right]^2\right)$$

$$B_i=\frac{\mu_{r,i}}{A_i\sigma^2_{r,i}}$$

$$C_i=\frac{\mu_{g,i}}{A_i\sigma^2_{g,i}}$$

$$D_i=\frac{\mu_{b,i}}{A_i\sigma^2_{b,i}}$$

Then, at run-time α_i can be computed by using:

$$\alpha_i=B_iI_{r,i}+C_iI_{g,i}+D_iI_{b,i}$$

By using a threshold on CD_i one can decide whether pixel $\boldsymbol{I_i}$ has similar chromaticity to the background pixel $\boldsymbol{E_i}$, whenever $\alpha_i<0$ pixel $\boldsymbol{I_i}$ can be classified as shadow.

Skin detection

Whenever a new object appears in the scene the region in which it is inserted will be considered background after a number of frames. But until that moment we would like to seperate hand from non-hand candidate regions. This is done by detecting skin. Again, there are several methods to detect skin [VEZ03]:

- Explicitly defined skin regions
- Nonparametric skin distribution modeling
- Normalized Lookup table
- Bayes classifier
- Self organizing map
- Parametric skin distribution modeling
- Single Gaussian
- Mixture of Gaussians
- Multiple Gaussian clusters
- Elliptic boundry model
- Dynamic skin distribution models

Of all these methods a Bayes classifier using a skin probability map (SPM) has the highest performance, meaning that it has a high rate (90%) of true positives and a low rate (14.2%) of false positives. Therefore we have chosen to implement this method.

This method is proposed by Jones et al. [JON02], a large dataset was created of 18,696 images which contained nearly 2 billion pixels. From these images 13,640 were used as training set. A subset of skin and a subset of non-skin pixel have been manually labeled. A histogram was used for classifying the two sets of pixels. The distributed probability distance is calculated as follows:

$$P(rgb)=\frac{c[rgb]}{T_c}$$

where c is the count in the histogram bin rgb and T_c is the total number of entries in the histogram. Using this formula skin and non-skin probabilities are calculated as follows:

$$P(rgb|skin)=\frac{s[rgb]}{T_s}$$

$$P(rgb|\neg skin)=\frac{n[rgb]}{T_n}$$

where s[rgb] is the number of counts in bin rgb of the skin histogram and c[rgb] is the numer of counts in bin rgb of the non-skin histogram. T_s and T_n are the total counts contained in the skin and non-skin histograms, respectively.

A pixel is then classified according to the following formula:

$$\frac{P(rgb|skin)}{P(rgb|\neg skin)} \geq \Theta$$

where $0 \leq \Theta \leq 1$ is used as a threshold. A low threshold leads to a high rate of true positives but also a high rate of false positives. Using a high threshold will lead to less false positives but also less true positives.

Also bin size is an important factor in performance, using a bin for each RGB value, that is 256^3 bins, leads to overfitting. According to [JON02] using 32 bins (a bin size of 8) leads to the best performance.

The dataset used for the histogram we used is the Compaq Cambridge Research Lab image-database, which is the same as in [JON02].

Hand detection

After segmenting the foreground from the background and detecting skin, the system still suffered from noise (see Chapter 7 for more details). To be certain that a hand is detected a matching algorithm is selected to verify whether there is a hand in the segmented foreground. A fast template matching method is used called fast normalized cross correlation. Fast normalized cross correlation is equivalent to normalized cross correlation except that it has a much lower computational cost. Fast normalized cross correlation is introduced by [LEW95].

If cross correlation is used one gets high correlations at locations where the intensity of the image is high. These correlations can be higher than at the actual location where the feature is located. Normalizing the image and feature can overcome this problem. Using normalized cross correlation the correlation coefficient is calculated as follows:

$$\gamma(u,v)=\frac{\Sigma_{x,y}[f(x,y)-\bar{f}_{u,v}][t(x-u,y-v)-\bar{t}]}{\left\{\Sigma_{x,y}[f(x,y)-\bar{f}_{u,v}]^2\Sigma_{x,y}[t(x-u,y-v)-\bar{t}]^2\right\}^{0.5}}$$

The numerator in (?) can be substituted by convolution in the frequency domain. Assuming that the mean of f and t have already been removed the numerator becomes:

$$\gamma_{num}(u,v)=\sum_{x,y} f'(x,y)t'(x-u,y-v)$$

where f' substitutes $f(x,y)-\bar{f}_{u,v}$ and t' substitutes $t(x,y)-\bar{t}$.

This is equal to a convolution where t' (-x,-y) is used instead of t', which can be computed by:

$$\mathcal{F}^{-1}\{\mathcal{F}(f')\mathcal{F}^*(t')\}$$

This reduces the complexity by a large factor . Using a search win the complexity of γ_{num} is approximately $N^2(M-N+1)^2$ additions/multiplications, for the convolution the complexity is approximately N^2M^2 additions/multiplications.

The intensity part - $\sum_{x,y}[f(x,y)-\bar{f}_{u,v}]^2$ (i.e. the normalizing part) can be computed by using the integral image (also known as running sum) of the image and the image square.

The image energy is then computed as follows:

$$s(u,v)=f(u,v)+s(u-1,v)+s(u,v-1)-s(u-1,v-1)$$

$$e_f(u,v)=s(u+N-1,v+N-1)-s(u-1,v_N-1)-s(u+N-1,v-1)+s(u-1,v-1)$$

Similarly the energy of the image square can be computed by substituting $f(u,v)$ with $f^2(u,v)$. This requires only approximately $3M^2$ operations.

Locating the finger

Once the hand is located, the exact location of the pointing finger needs to be extracted. The user is positioned at the bottom of the desk, the assumption is made that the user will always point upwards. Then the tip of the finger will always be at the highest y-value in the acquired frame.

Since the image is floodfilled to create a mask for the background subtraction locating the finger tip is done in the same iteration. When the highest y-value is found a check is made whether the point found is part of the finger tip. From the last 8 rows the width of the filled area is checked. Whenever the width is higher than 8 pixels the found location will not be considered a finger tip. Normally the width of a fingertip is between 3 and 6 pixels.

From the x-coordinates of this strip the middle of the finger is calculated by summing the x-values and dividing the total by the number of x-values.

The advantage of this approach that the finger with which one is pointing does not necessarily needs to be the index finger. Figure 2 shows an example of a located finger.

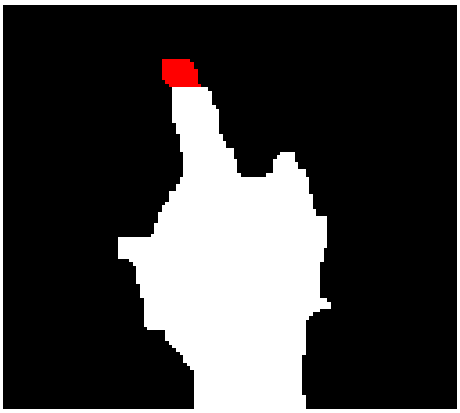


Figure 2: Located fingertip, the red area indicates the 8 highest rows in the filled blob

Document Detector

The document detection part is one of the main components in the system. Its task is to detect documents in the viewfinder image. After a document is detected in the viewfinder image the document detector should capture the document from a high resolution image and then rectify these documents. After the documents are rectified, they should be saved to disk and added to a database of documents together with a possible pointing location. Each of these steps will be discussed in this section.

Document Detection

The first step in capturing a document is knowing that a document actually is present in the viewfinder image. To detect a document a number of methods are available. These methods include, background color differencing and background gradient differencing.

Background color differencing is a method which is very intuitive. Each pixel color in the viewfinder image is compared to the same pixel in a background image. This comparison is done in the RGB space. The color difference is the Euclidean distance between the to pixel colors. When the color distance between to pixel is larger than a certain threshold the pixel is considered foreground. Although the approach is intuitive and easy to implement it has a few drawbacks. The first drawback is the sensitivity to noise. If a shadow or a highlight appears in the viewfinder image the pixels inside this shadow or highlight are falsely classified as foreground pixels. Another problem is the fact that when a document is places in the viewfinder image of the camera the lighting will change, causing the camera to adjust its white balance and exposure settings. This will cause a global color change in the viewfinder image which could result in the entire image appearing as foreground.

Because of these problems another approach was used for detecting possible foreground objects in a viewfinder image. This second approach also uses differencing of the current image and the background image. However this approach does not use color information directly to classify a pixel as foreground or background. Instead it first creates a gradient image of both the background and the viewfinder image using a simple Sobel kernel [-1 0 1] in both horizontal and vertical direction. The next step is subtracting each gradient pixel of the background from the gradient pixels in the viewfinder image. The result is an image with gradients which only appear in the viewfinder image and not in the background image. Gradients which exist in the background and not in the viewfinder, which may be caused by objects being removed from the desk, become negative gradients in the difference image. The difference image is then thresholded so only strong gradients are kept. The advantage to color differencing is that global color changes do not influence the gradient images and thus will not cause the entire image to be classified as foreground. Also shadows and highlights are removed because they rarely contain any sharp edges.

The gradient image now contains all the lines of the foreground objects in the viewfinder image. These objects do not always have to be documents but can also be other items places on the desk. To detect what lines could be that of documents straight lines need to be found that could make up a document. The lines are detected by doing a Probabilistic Hough transform. The result is a set of straight lines in the document, each represented by a start and end point. These lines are then clustered so double lines and close lines are removed. If a document exists in the set of lines it can be assumed that a document is surrounded by four lines. To technique used for finding enclosed areas is by iterating through the set of lines matching end points of one line with the start point of another line. When an end point of a certain line reaches the start point of the first line the algorithm return the area enclosed by these lines as a document.

Document Rectification

For each document detected in the viewfinder image the set of cornerpoints are saved according to [ZHA03]. Next the document detector acquires a high resolution image from the camera. On this high resolution image the actual document rectification is performed. The coordinates of the cornerpoints of a document are scaled to match the same points in the high resolution image. By scaling these points precision can be lost due to rounding errors or viewfinder deviation with respect to the high resolution image. In order to (re)gain accuracy the document detector will try to detect the position of the document corner in the high resolution image. This is done by extracting a patch from the high resolution image for each cornerpoint. The center of each patch is the scaled location of the cornerpoint from the original viewfinder image. In this patch edges and lines are detected by using the same methods as with document detection stage. The crossings of all the lines are calculated. The point with the most crossings is considered to be the exact cornerpoint of the document. Doing this results in less noise and parts of the background at the borders of the document.

After the detection of the cornerpoints the algorithm rectifies the image to eliminate distortion caused by projection. For rectification of the document the method in [ZHA03] where used. The method uses the standard pinhole model to model the projection from a space point M to an image point m as show in Figure 3.

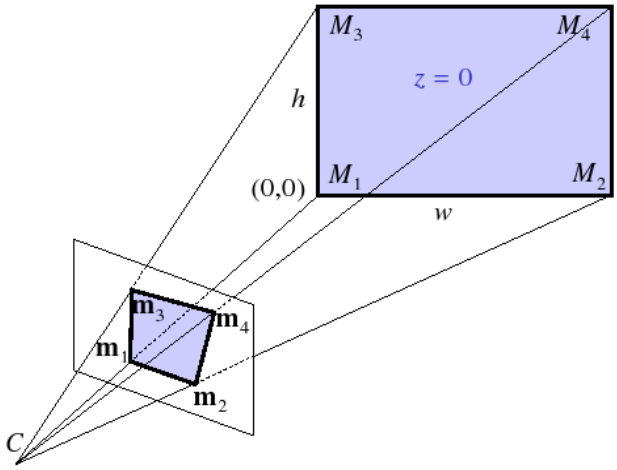


Figure 3: Conversion from image to space points

Let the width and the height of the rectangular shape be *w=1* and *h=w/aspect_ratio.* Let the coordinates of the four corners, M_i (i = 1..4), be (0,0), (w,0), (0,h), (w,h) in the plane coordinate system (z = 0). The rectangle is projected in the image as a quadrangle with the corners $\boldsymbol{m}_i$ (i = 1..4) respectively. A vector $\tilde{\boldsymbol{x}}$ is the vector $\mathbf{x}$ with an augmented 1. For example $\tilde{\boldsymbol{x}} = [x_{1,\ldots}, x_n, 1]^T$ if $\boldsymbol{x} = [x_{1,\ldots}, x_n]^T$.

The first step in rectification of the document is calculating the focal distance of the camera. This is needed to get the aspect ratio of the original document. When assumed that all pixels are square (s = *0*), and the principal point is at the image center (u_0 = *0* and v_0 = *0* with image positions in the range from x = [-width/2 ... width/2] and y = [-height/2 ... height]).

The focal point can be then be defined by: $f^2 = \frac{-n_{21}n_{31} + n_{22}n_{32}}{n_{23}n_{33}}$

Where n_{2i} (resp. n_{3i}) being the *i*-th component of $\boldsymbol{n_2}$ (resp. $\boldsymbol{n_3}$).

Where $\boldsymbol{n_2} = k_2\tilde{\boldsymbol{m}}_2 - \tilde{\boldsymbol{m}}_1$ having $k_2 = \frac{(\tilde{\boldsymbol{m}}_1 \times \tilde{\boldsymbol{m}}_4)\cdot\tilde{\boldsymbol{m}}_3}{(\tilde{\boldsymbol{m}}_2 \times \tilde{\boldsymbol{m}}_4)\cdot\tilde{\boldsymbol{m}}_3}$,

and $\boldsymbol{n_3} = k_3\tilde{\boldsymbol{m}}_3 - \tilde{\boldsymbol{m}}_1$ having $k_3 = \frac{(\tilde{\boldsymbol{m}}_1 \times \tilde{\boldsymbol{m}}_4)\cdot\tilde{\boldsymbol{m}}_2}{(\tilde{\boldsymbol{m}}_3 \times \tilde{\boldsymbol{m}}_4)\cdot\tilde{\boldsymbol{m}}_2}$.

A solution for *f* does not exists when $n_{23} = 0$ or $n_{33} = 0$.

The aspect ratio is then given by the equation: $\left(\frac{w}{h}\right)^2 = \frac{\boldsymbol{n_2^T A^{-T} A^{-1} n_2}}{\boldsymbol{n_3^T A^{-T} A^{-1} n_3}}$,

where $\boldsymbol{A}$ is the intrinsic matrix defined by: $\boldsymbol{A} = \begin{bmatrix} f & 0 & u_o \\ 0 & sf & v_0 \\ 0 & 0 & 1 \end{bmatrix}$.

The next step in rectification of the document is the calculation of the projection matrix $\boldsymbol{P}$. To get this projection matrix we need to solve:

$$\boldsymbol{P}\begin{bmatrix} x \\ y \\ 1 \end{bmatrix} = \lambda\begin{bmatrix} u \\ v \\ 1 \end{bmatrix} \text{ which is equal to } \begin{aligned} P_{(0,0)}x + P_{(0,1)}y + P_{(0,2)} &= \lambda u \\ P_{(1,0)}x + P_{(1,1)}y + P_{(1,2)} &= \lambda v \\ P_{(2,0)}x + P_{(2,1)}y + P_{(2,2)} &= \lambda \end{aligned}$$

Substituting λ in the first to equations gives:

$$-xP_{(0,0)} - yP_{(0,1)} - P_{(0,2)} + xuP_{(2,0)} + yuP_{(2,1)} + uP_{(2,2)}$$
$$-xP_{(1,0)} - yP_{(1,1)} - P_{(1,2)} + xvP_{(2,0)} + yvP_{(2,1)} + vP_{(2,2)}$$

This yields eight equations if this is done for all four cornerpoints of the document. If written in the matrix notation:

$\boldsymbol{M}[P_{(0,0)}, .., P_{(2,2)}] = 0$ with $\boldsymbol{M}$ a 8x9 matrix.

To solve this equation the eigenvectors of $\boldsymbol{M^T M}$ are calculated. The eigenvector which belongs to the eigenvalue 0 contains elements of the projection matrix that can be used for rectifying the document.

With projection matrix $\boldsymbol{P}$ the coordinates in space (x,*y*) can now be calculated back to images coordinates (*u*,*v*) with *u* in [0..*h*] and *v* in [0..*w*].

$$u = \frac{P_{(0,0)}x + P_{(1,0)}y + P_{(2,0)}}{z} + \frac{width}{2}$$
$$v = \frac{P_{(0,1)}x + P_{(1,1)}y + P_{(2,1)}}{z} + \frac{height}{2}$$

where $z = P_{(0,2)}x + P_{(1,2)}y + P_{(2,2)}$

By adding half of the width and height to both *u* and *v* respectively, the locations are now in 'normal' image space starting at (0,0). Bilinear interpolation is used for improving image quality because the *u* and *v* values are not likely to match exact pixel locations in the original image. The result is now a rectified document from the original image.

6.Implementation

The CamCap application, which is described in this paper, is build on the previous version of the CamCap software. Because of this, only newly implemented parts of the system will be described in detail. Common parts will only be referenced to, or, if needed for clarity, briefly described.

CamCap

The central part of the application is the class CamCap as shown in Figure 4.

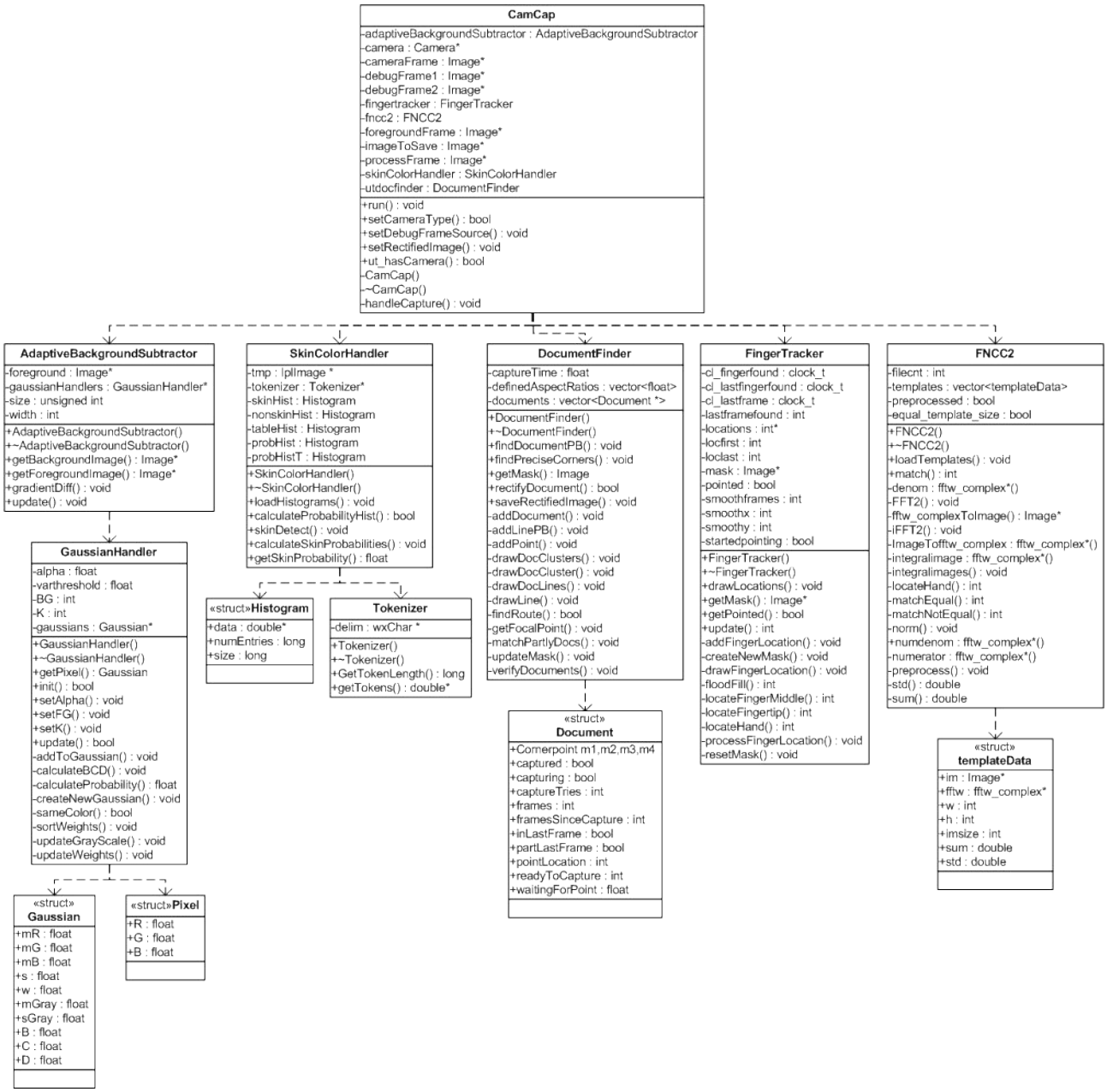


Figure 4: Simplified class diagram of the CamCap application

This class is responsible for the dataflow of the system. In each iteration of the system, the class CamCap executes a set of operations as shown in Figure 5.

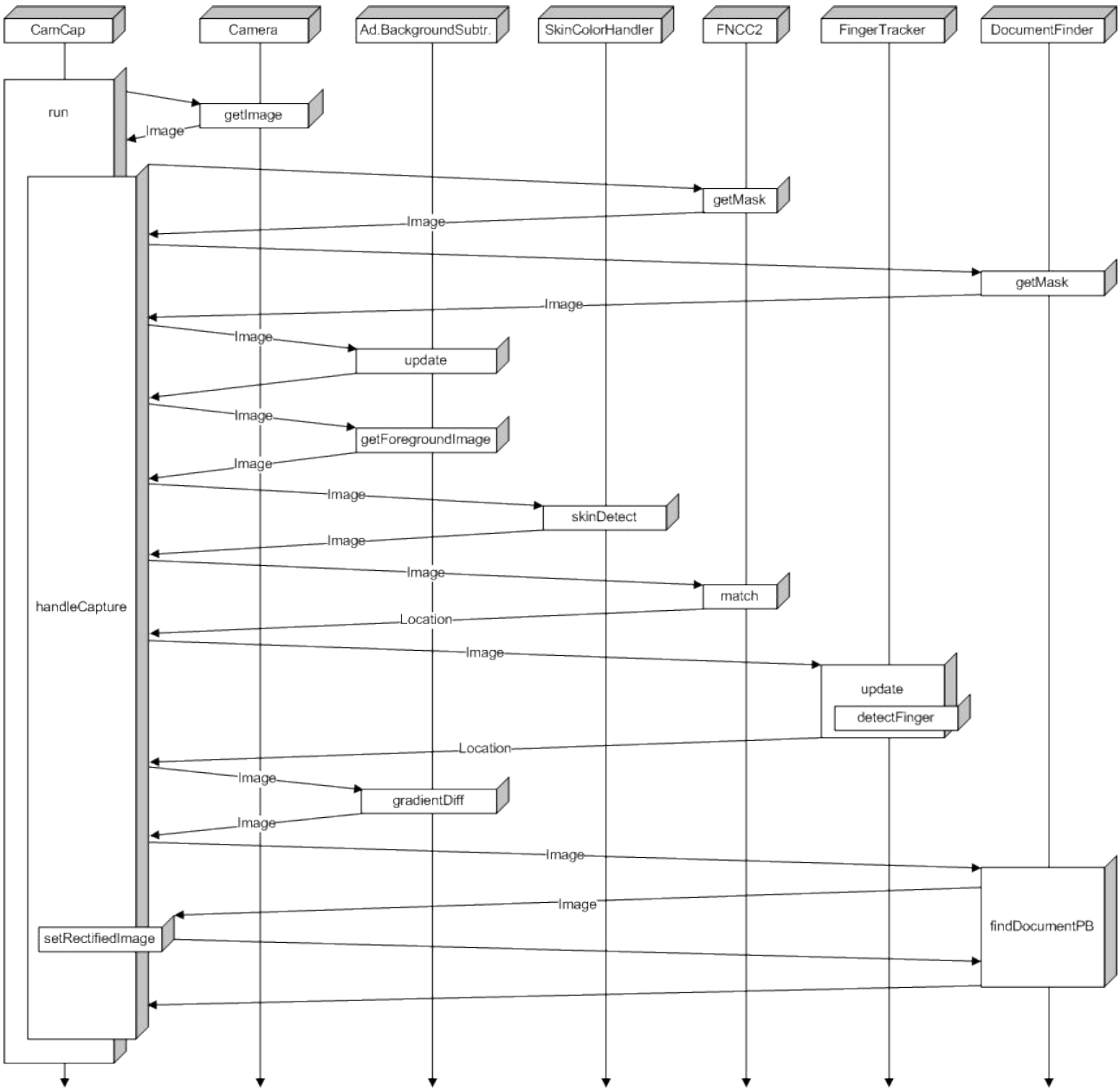


Figure 5: Simplified sequence diagram of the CamCap application

In each iteration CamCap requests an image from the current camera. The camera object, which in the current version of CamCap can be a FileLoader, Canon A620 or Canon S50, returns an Image pointer of the current frame. This frame is now used throughout the rest of the iteration. The next step is to update the AdaptiveBackgroundSubtractor instance. This will cause the background subtracter to analyze each pixel in the image and compare them with its Gaussians as described in Chapter 5. However not all pixels should be learned as background. Detected documents and hands, which can be stationary in the image for a longer period of time, should always stay in the foreground. This is implemented using a mask image as an optional parameter. Each red pixel in the mask which is larger than 0 (each pixel has a range of 0 to 255) is not learned in the update call but simply classified as a foreground pixel. The mask which is supplied to the update function is a combination of the masks returned by the `getMask` function in both FNCC2 and DocumentFinder.

After the background has been updated the application requests the foreground image for further processing. This foreground image is updated on each `update` call since each pixel is already classified as background or foreground. The function `getForegroundImage` returns an Image pointer without the need to do any extra computations. The foreground image is a color image that is equal to the camera frame, however all pixels classified as background are made black.

The foreground image is now used to detect skin colored pixels. This is done with the use of three different histograms. One histogram contains pixel colors of human skin samples and the second histogram contains non-skin colored pixel colors. The third histogram should only be used on backgrounds with a color that is close to skin color, for example red wooden tables like the one used with the development of this application. The result is a binary picture, with all skin colored pixels displayed as white pixels, and all non-skin colored pixels black like the figures shown in Table 3.

This binary skin image is than passed to the FNCC2 class which will try to match some hand models to it. This is done using fast Fourier transforms and normalized cross correlation as described in Chapter 5. If a hand is found in the image the function will return a pixel location in the image which can be used to locate the fingertip in the same binary image. The fingertracker will locate the fingertip using a floodfill algorithm by calling the `detectFinger` function. The mean x-value of last few top rows of filled pixels is considered to be the fingertip. The location is then updated in the finger tracker. Whenever a fingertip is found to be stationary at a position for a period of time the finger tracker will not only return the position of the fingertip but also a boolean telling the system that a 'pointing-event' has occurred.

The last series of steps in each iteration take care of detecting a document and rectification of this document if one is found. The first step in detecting documents is creating a gradient difference image by calling `gradientDiff` from the background subtracter class. This function creates two gradients images, one from the current strongest background, and one from a gray scale camera frame. The gradients of the background are then subtracted from the gradients of the camera frame. The result is an image will gradients values in the range of -255, if a very strong gradient was present in the background and no gradient was present in the camera frame, to 255, if a gradient is only visible in the camera frame. A thresholded image is returned to the CamCap instance for further processing.

The processing of the gradient difference image is done in DocumentFinder by calling the `findDocumentPB` function. This will find straight lines in the gradient image by using a Hough transform, and processing all the found lines as described in Chapter 5. If a document is found the DocumentFinder queries the camera for a high resolution image on which further processing can be done. This processing is done in a different thread to allow the program to continue while rectifying the document, which can be a time consuming job. When the thread finishes processing it will wait for a mutex in CamCap after which it will call a function in the CamCap class, which sets a pointer to the rectified image. Each time an iteration of the application restarts it will check if the pointer is set. If so, it will save the image to disk and clean up the pointer. This last step is done by the main thread because disk access in any child process tends to be very slow. Using the mutex ensures only thread is allowed to set the pointer to the rectified image without any other thread overwriting any unsaved data.

7.Evaluation

Since all parts are already tested in other research it is not our aim to test the performance and accuracy again but whether they are applicable to our problem. Also we will try to find suitable values for the learning rates. The background subtraction and the skin detection can be tested separately, since the hand detection and finger detection depend on the result of the other parts these will not be tested separately.

Background detection

For testing the background subtraction the important factor is the learning alpha. This sets the speed with which foreground eventually emerges with the background. Using a too high alpha will result in that hands and documents will be part of the background before they are detected. Or when they are not detected for a number of frames they also become background very fast. Using a too low alpha results in new parts of the foreground that ought to be background become part of the background too slowly. This can result in noisy foreground images.

We tested the background detection by inserting an object into the viewfinder after 80 frames. Then the number of frames is counted until the object has become part of the background.

α	#frames
0.005	140
0.01	50
0.05	20
0.1	11
0.2	6
0.3	4
0.5	2

Depending on the framerate of the iDesk an α will be selected.

Table 1 shows a sequence of frames with the subtracted foreground. There are is only some random noise. Area's where there is a shadow are also considered foreground. Whenever a user points on the iDesk he will always create a drop shadow (which can be seen in Table 3). Therefore shadows need to be detected and removed from the foreground image.

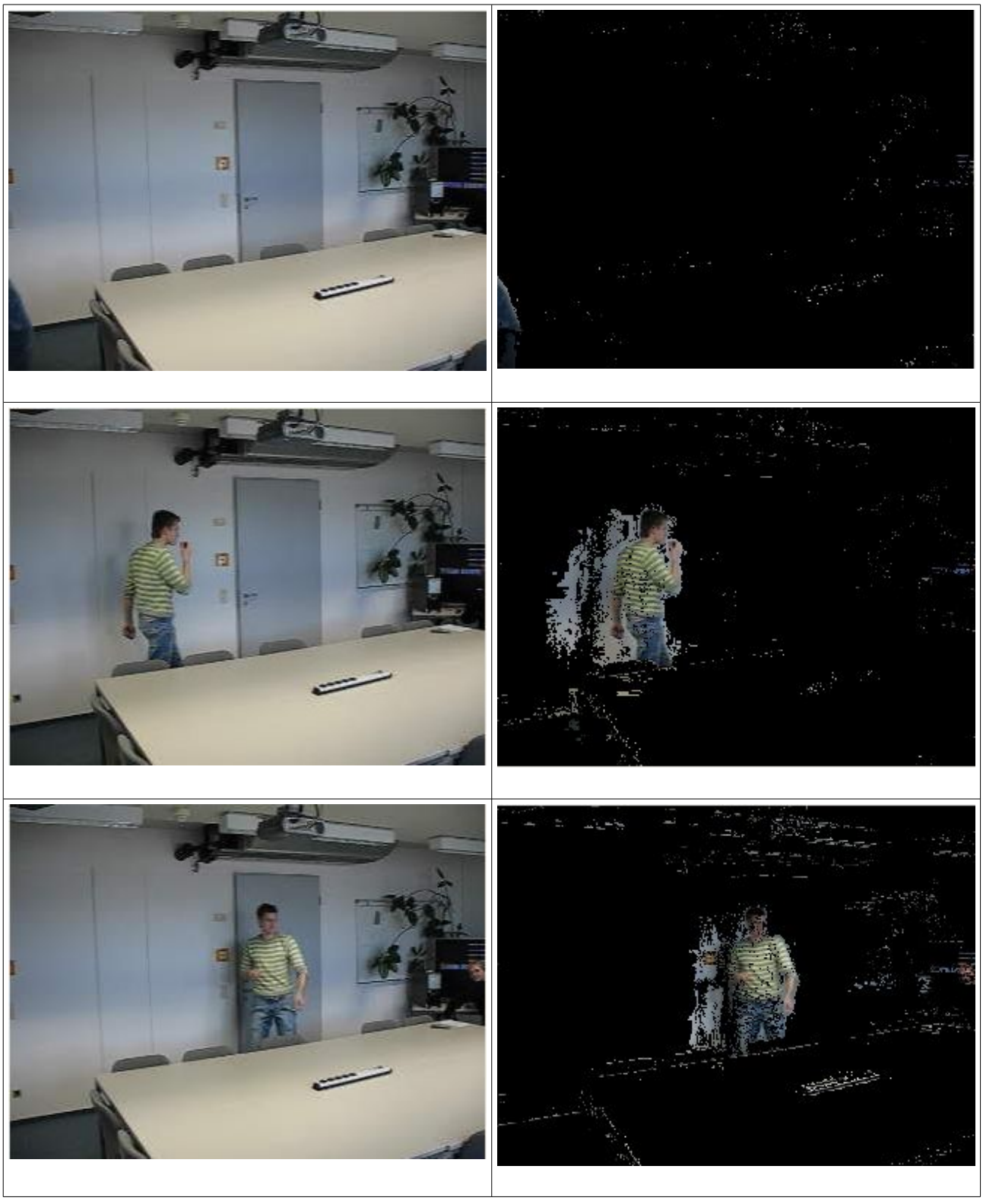


Table 1: Background subtraction

Shadow detection

Next we added the shadow detection to the background subtraction. As can be seen in Table 1 there is noise in the shadow area in the background subtraction without shadow removal. Table 2 shows the result of shadow removal added to the background subtraction. This reduces the noise created by shadows to a minimum.

Table 2: Background subtraction with shadow removal

Skin detection

The skin detection uses a thresholded function to decide whether a pixel value is skin color. Whenever the threshold is too high the performance will be poor but the number of false positives will be low. Whenever the threshold is set too low there will be a high rate of false positives.

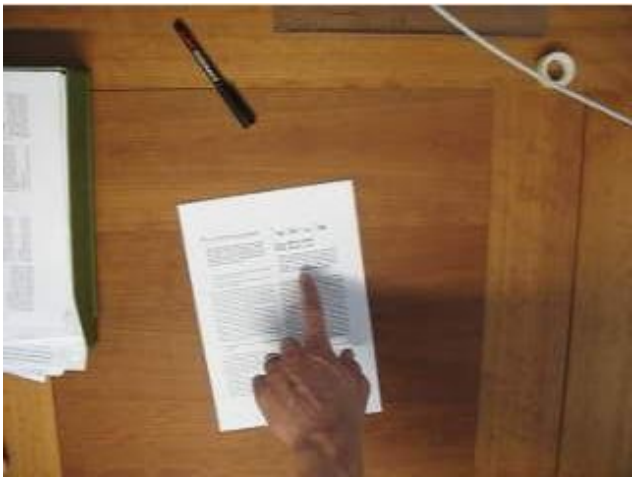
From the first tests we learned that the colors of the iDesk has too much overlap with skin color. Therefore we created an extra histogram of the iDesk by manually selecting pixels under different lighting conditions. A histogram of 32x32x32 bins (RBG) was trained on this data. The iDesk histogram can be seen as an addition to the non-skin color histogram.

The optimal performance of the skin color histogram is reached when a threshold of $\Theta > 0.4$ is used [JON02]. The skin detection is tested on different lighting

conditions:

- Artificial light, high intensity
- Artificial light, low intensity
- Day light
- Both artificial light and daylight

From these test we learned that the performance did not differ much under the different lighting conditions.
As can be seen in the examples of table 3 the skin detection the performance of the skin detection has a high rate of true positives. But there is also a moderate rate of false positives. This supports our conclusions based on previous work.



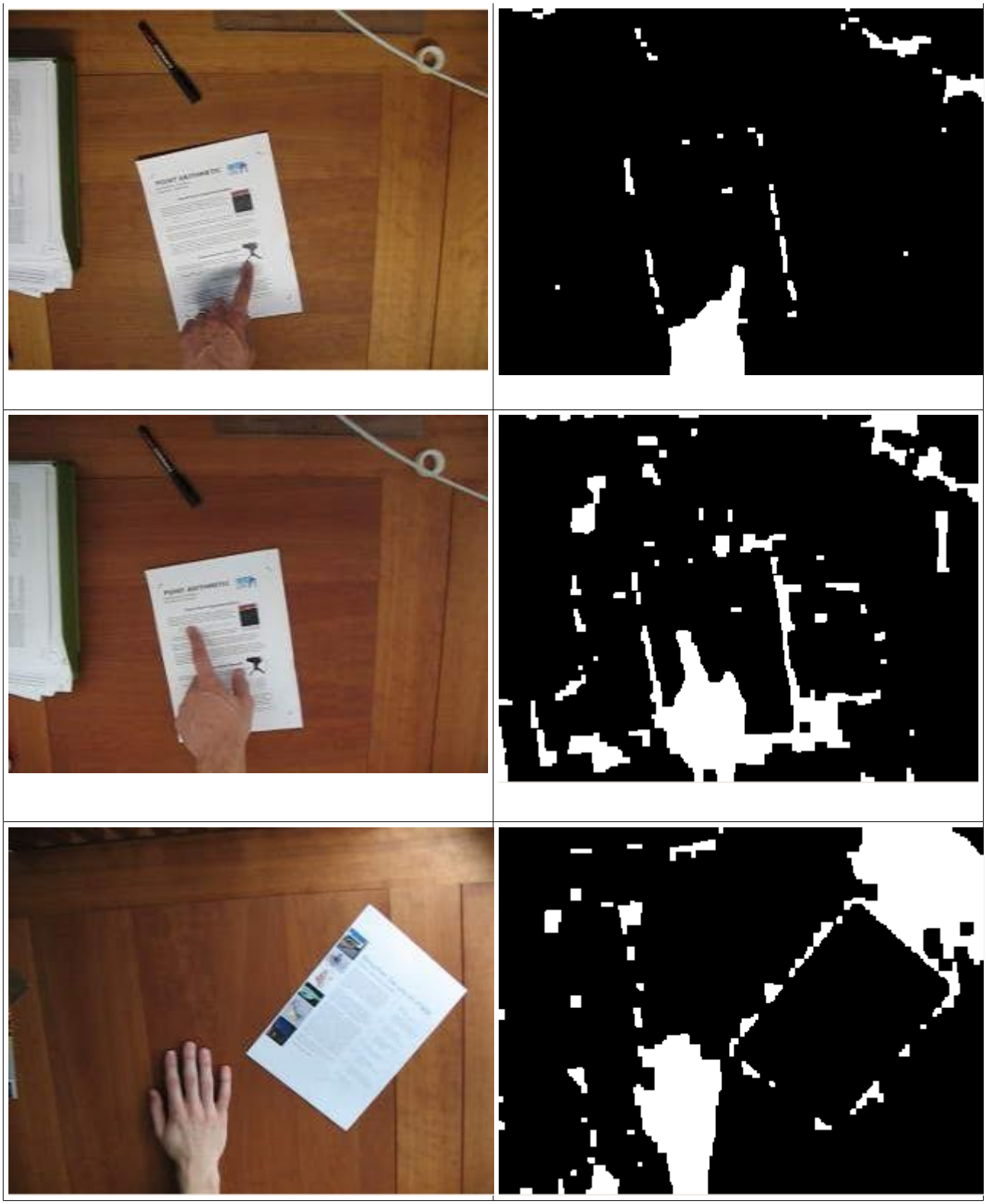


Table 3: Skin detection under different lighting conditions

Background detection combined with skin detection

Next we evaluate the performance of the background subtraction combined with skin detection. First the background is subtracted, then on the foreground image the skin is detected, the result is a binary image. the white pixels represent foreground and skin pixels, the black pixels are background and/or non-skin pixels. This also tested in different conditions. Table 4 shows a result under two different conditions. As can be seen the noise is removed in these images, although occasionally there is some noise this is mostly a couple of pixels.

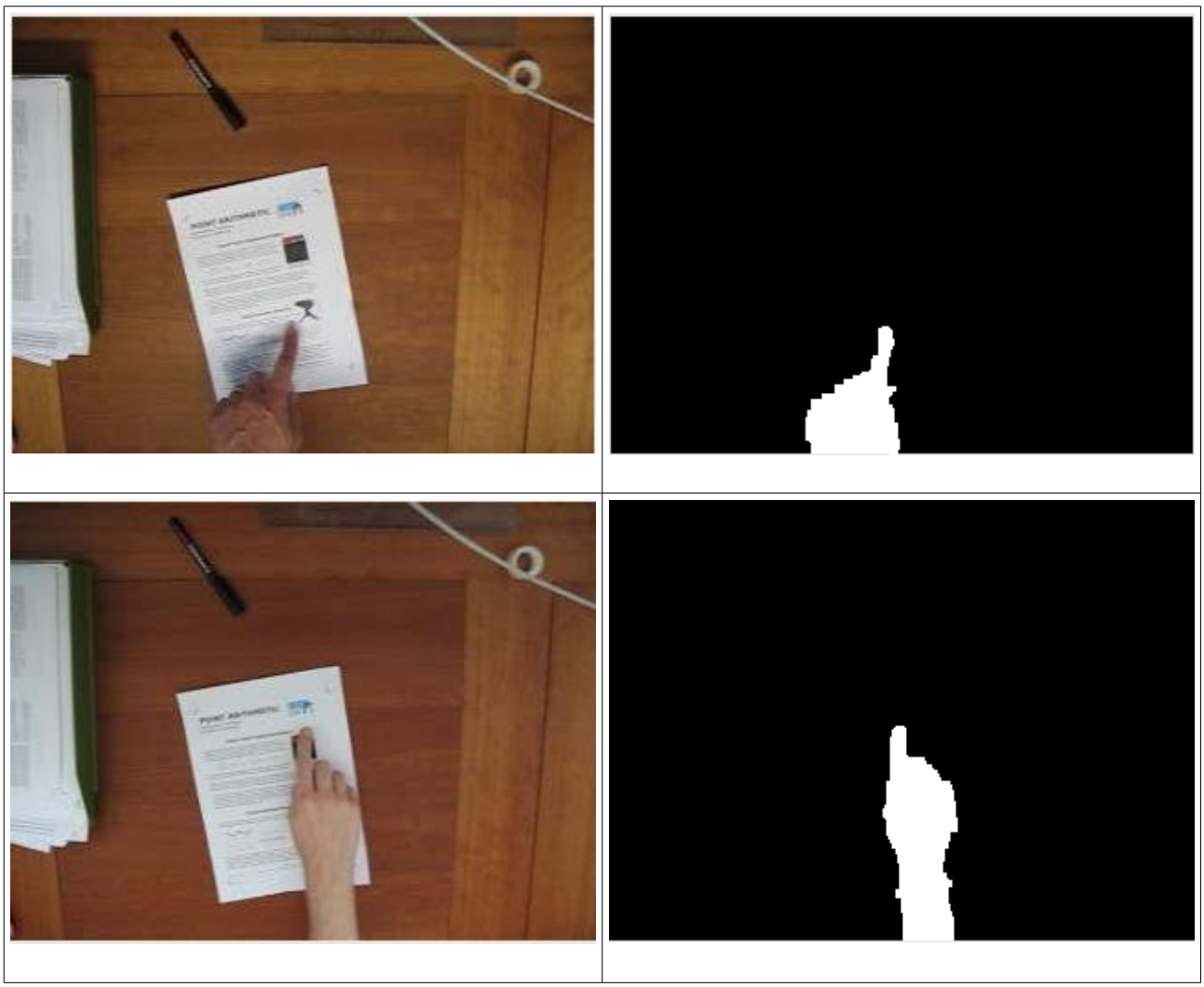


Table 4: Combined background subtraction and skin detection

Hand detection

Whenever the hand is segmented from the background the result will be a binary images in which the hand consists of white pixels and the background is black. To match the hands two models are created, one for the left hand and one for the right hand. For the hand detection it is more important to find a maximum of true positives because false positives will be detected when the finger is located. Therefore the test is focused at the true positives.

The tests of the hand detection were done on the binary images which are the result of the background subtraction and the skin detection.

The aim of this test is to learn whether the hand detection is able to detect different hand types (i.e. different in size and finger length) using the two hand models.

To test different hand types 10 subjects were taken with different hand characteristics. The subjects pointed for about 2 minutes in the viewfinder. Then the number of times that the hand was not found was measured. It is hard to measure the exact rate of false detection, therefore the rate was estimated by observation.

Only for 1 of the 10 subjects the performance was poor, the detection rate was about 60%. For the other subject the performance was 90% or higher.

Locating the finger

Whenever a hand candidate is found the blob is searched for a fingertip. It is important to reduce the number of false positives to a minimum because this is confusing users. Reducing the number of false positives will result in less true positives but this should be less important if the user knows the fingertip is not found. This depends on the quality of the feedback.

Again 10 subjects were taken to test the performance, the rate of correct fingertip detected was measured whenever the hand was detected.

Table 5 shows an example of a detected finger, the red area indicates the location of the fingertip.

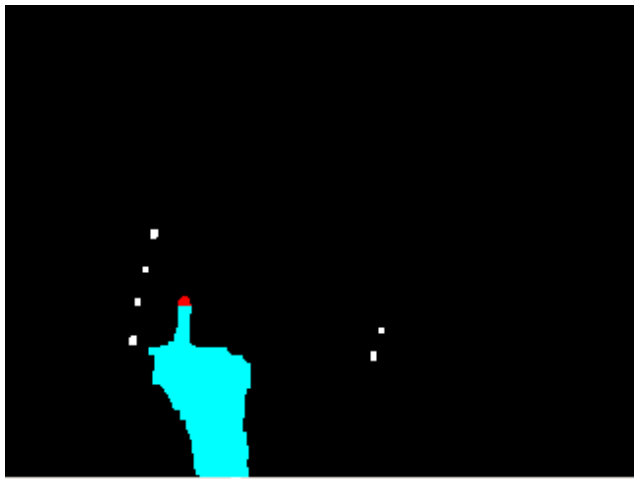
	

Table 5: Finger detection results

Document detection

Detecting documents in images is done by detecting lines in images. These lines are found using the gradients that are present in the current camera frame and are not present in the background image. A Hough transform is used to detect straight lines in the gradient image. The gradients are thresholded before doing the Hough transform. A low threshold will result in a high number of gradients and may lead to false document borders in the image see Figure 8. Setting the threshold to high will result in broken lines or no lines at all which can be seen in Figure 7. The threshold used in the CamCap application was chosen after a series of tests.

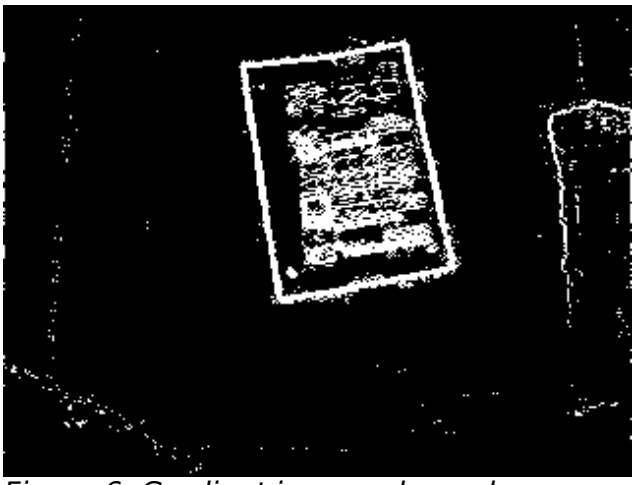


Figure 6: Gradient image when a low gradient threshold is used

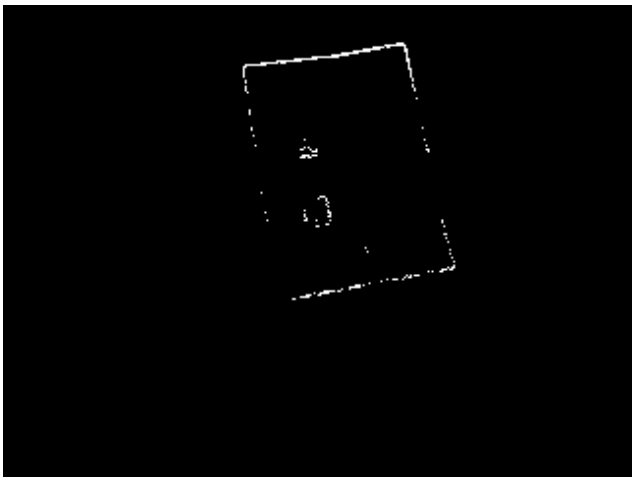


Figure 7: Gradient image when a high gradient threshold is used

The threshold for the minimal gradient strength used in CamCap is 50. The gradient is now used in a Hough transform to detect straight lines in the image. The Hough transform also uses three different thresholds for the line detection. The first threshold in the Hough function defines the minimal line weight. The second and third parameters define respectively the minimum and maximum length of the detected lines.

The result of settings the first threshold to a low value causes the system to detect small thin edges as document boundary. A high value on the other hand causes the system not to except any edges but extremely strong ones. Detecting thin lines however does not cause a big drop in accuracy. Detecting no lines however causes many documents to stay undetected. The first threshold in our application is set to 40 which seems to give a good performance. The last two thresholds give a range of line lengths which are allowed to be detected. These values can be set to a wide range of values depending on what type of documents is worked with.

Document Rectification

The goal of the document rectification is to eliminate projection transformation and rotation of the document in the captured image. Because intrinsic parameters of the camera where unknown the exact mathematical solutions where not checked. Instead the checks where done by visually inspecting the rectified documents for errors or incorrectness. By letting the system capture a document with a raster printed on it, the correctness of the document can be checked by checking if all the lines of the corrected raster are exactly horizontal and vertical. The test case setup can be seen in Figure 6, the result can be seen in Figure 9.

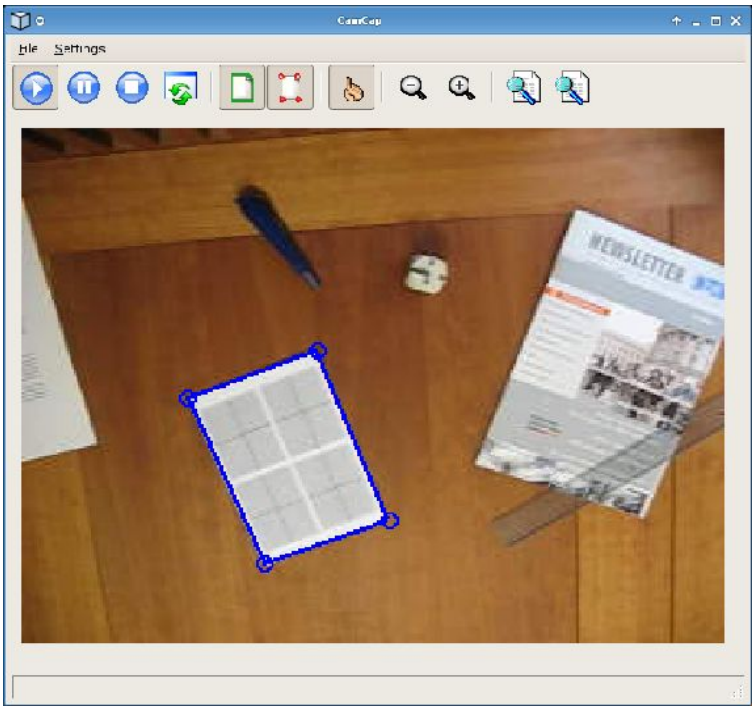


Figure 8: Test setup document rectification

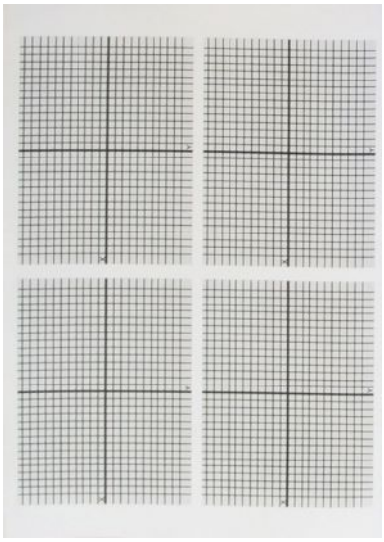


Figure 9: Rectified test document

8.Prototypes

During the project two prototypes were developed. The first version was the primary version based on the last version of CamCap, but with the added functionality described in this report. This version was used to do the first series of user tests on. The second prototype was developed based on the first prototype but with the added knowledge gained from the user tests. This second prototype was then used for the second series of user tests. Both prototypes were also tested using two different settings with respect to the user input. The first subversion of each prototype used a ten second time limit for the program to wait for a pointing event in a document. If a hand is found and the fingertip is located in a document the application will wait until the fingertip is out of the document for a period of two seconds before initiating the capture. The second subversion of each prototype waited an unspecified period of time for a pointing event to occur in a document before capturing it. Like in the first subversion the capture will only be initialized after a fingertip is not found in a document for a period of two seconds.

First Prototype

Although visibly not much had changed in the first prototype if compared with the last version of CamCap, there still were some changes that influenced the users while using it. The processing frame displayed in the left top corner of the screen gave visual feedback to the user what happened with respect to document detection and fingertip tracking as shown in Figure 10.

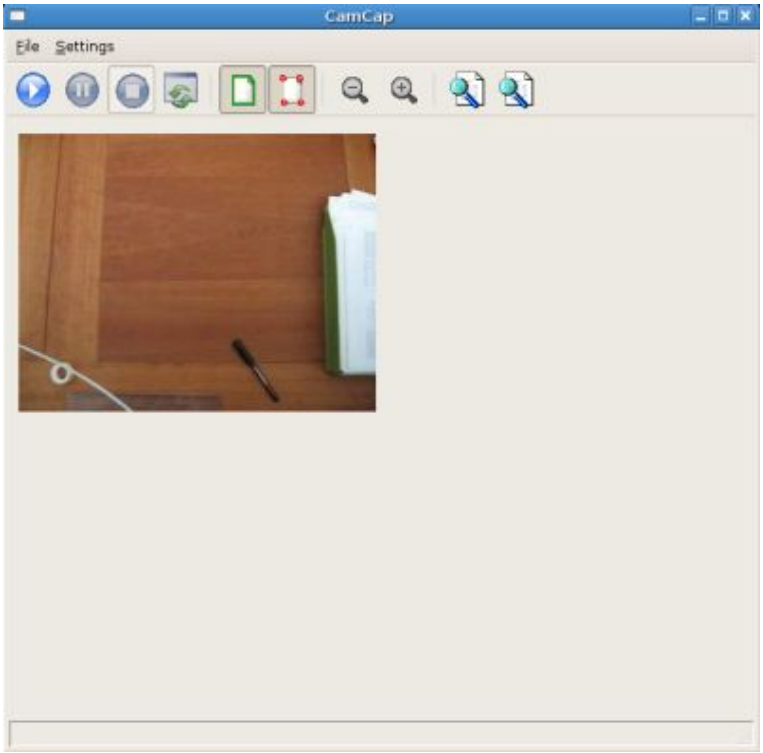


Figure 10: Graphical User Interface of the first prototype

The visual feedback of the document detector consisted of drawing a rectangle around every detected document. The rectangles changed in colors whenever a document changed state internally in the application. The meaning of each color was:

- Red Document probably detected
- Orange Document detected and its location is stable
- Blue Capturing and processing the document
- Green Document captured and processed success

A user could start pointing at a document when it turned orange, meaning a document was detected at a stable location for at least 10 frames. The feedback during the pointing action consisted of a circle around the fingertip. The circle changed color representing the internal state of the fingertip in the system. The color around the fingertip meant:

- Red Fingertip detected
- Orange Fingertip stable at a location for 1.5 seconds
- Green Pointing event occurred, fingertip stable at a location for 3 seconds

When the user pointed at a location for three seconds the circle would turn green, representing that the user can retract its finger. After the user would retract its finger from the document the system captures the document and starts processing, showing a blue rectangle around the document. After rectification on the document the rectangle would turn green.

9.Usability study I

Setup

To test the usability of the first prototype a study is conducted. The goal was to learn whether users were comfortable using the pointing gesture and how well they were able to use the prototype. The study was qualitative usability study which consisted of three smaller tests followed by a questionnaire and a short discussion. Although we used only 5 subjects the questionnaire still can give an indication about the strengths and weaknesses of the system.

The first test was to measure the learning curve of the subject, without the subjects knowing how the system works. We asked them to put a document in the viewfinder and wait until the rectangle around the document turned orange and then try to point in the document. The result should be that the document is captured. Also this test is to learn which 'click gesture' the subject would expect.

The second test was to test the usability of the first of the two interactions: when a document is detected by the iDesk it waits for 10 seconds after the document is colored orange after which the application captures the document.

The third test was to test the usability of the second interaction: when a document is detected the system waits until a user has pointed or the finger detection is turned off.

During the test an observation was made according to these criteria

1. Switching of attention between computer screen and desk.

   Switching attention very often is very likely to confuse the subject. This also indicates that the provided feedback is not sufficient.

2. Learning curve.

   A short learning curve indicates that the interface is very intuitive.

3. Position of hand(s) while not pointing.

   If the subject leaves his hand in the viewfinder the hand will become part of the background. This results in that pointing gestures will not be detected in that area.

4. 'Clicking gestures'

   If subjects use a different gesture to indicate a mouse click than the one provided that gesture should be considered as the new 'click gesture'. This mainly depends of the feasibility to implement that gesture. For example implementing a tap is very hard if not impossible for the iDesk.

5. Unintentional moving of documents on the desk.

   A document might stick to the hand of the user, then the document will be moved for a few centimeters. The result is that the document is detected again.

6. Errors

All information that the subjects needs to perform the tests was put in a document together with the questionnaire. By using a document all users have the same knowledge when the perform the tests. The document (including the questionnaire) can be found in Appendix A.

Tasks

For the first test we asked the subject to put one document in the viewfinder and point at the image in the document. The document should be captured.

For the second and the third test we asked the user to put two documents in any order in the viewfinder and point in one of them. Both documents should be captured.

Results

Questionnaire

All subjects noticed the different colors on the document and the finger except for one. He only noticed the colors on the fingertip. Most subjects were able to guess the representations of the used colors in the interface. Only the blue color around the document was missed by most users. All users pointed and waited for feedback.

Subjects who had a good understanding of the system and were able to interact quickly with it preferred the first of the two types of interaction. Subjects who did not understand how the system worked or did were not very fast with the interaction (slow reaction to the feedback) preferred the second type of interaction.

Most users liked the system and thought it was useful. The colors and their representations were clear to the subjects. The weak point was the quickness of the feedback, all subjects indicated that it was too slow. Even though they liked to use the system and though the interaction was natural. The combined results of the questionnaires can be found in Appendix B.

Suggestions for which applications the subjects would like to use iDesk for were: capturing documents, capturing images (in documents), games (e.g. chess) and capturing references.

Observations

The results of the observations are discussed according to the criteria.

1. The subjects mostly switched their attention whenever they put a document in the viewfinder. When the user pointed at a point in the document at first he looks at the document on the desk then points and switches to the computer screen. Also whenever the iDesk did not detect the finger the subjects switched frequently between the the desk and the computer screen.
2. In the first test it took about 5 minutes before a subject figured out how to use the system. The most difficult was to learn that whenever the rectangle around the document was red they were not allowed to point in the document. Most users tried to point right after the document is detected. Also the difference between the red and orange of the rectangle was not very clear.
3. All users put their hand (with which they pointed) at the bottom of the desk. This was outside the range of the viewfinder.
4. Most subjects pointed in the document and waited until something happened. Although most subjects eventually realized that the document could not be captured when they were pointing in it, it took quite some time before they figured this out. Most users did notice that the circle turned green on the detected finger but did not react by retracting their hand.
5. This did not happen very often, but when a subject did move the document he felt 'bad' about it. They thought they did something wrong.

6. The most common error was that the subjects pointed in the document when the rectangle around the document was still red. Even when they knew that they should wait until the rectangle turned orange they still made this error.

   Another problem that often occurred is that in the green circle int the document (which represents the selected point) was confusing to the user.

Discussion

Most subjects found that the size of the window with the camera view was too small. They had move towards the screen to see the feedback clearly. Also they did understand the representations of the different colors but found it hard to use these correctly. Also users had to wait very long until they could point in the document and the document was detected.

Conclusions

To improve the iDesk there are a number of changes can be made.

- The feedback that the pointing gesture is finished should be improved.
- The number of colors used to indicate the state of the system should be reduced.
- The time-span before the user can point in the document should be removed.
- The pointing gesture should be detected faster.
- The window which shows the camera view should be larger.
- The indication where the user pointed and the indication where the finger is detected should be different.
- Unintentional moving of the document should be detected.

10.Prototypes (2)

Second Prototype

After the first usability study (see Chapter 9) a number of changes were made to the application to simplify the user interaction with the application. Not all recommended changes are implemented. This because of the limited time available. Changes to the user interface (see Figure 11) included:

- Larger display area for the processing frame
- Filled circles on the fingertip
- Audio feedback when a pointing event occurred in a document
- Drawing a cross when a pointing location occurred in a document
- Less colors on the fingertip and documents
- Reduced time-span for finger point gesture.

Because of the larger display area of the processing frame the user could more easily see what the system was doing. Also the filled circles around the fingertip were used to improve visibility in the interface.

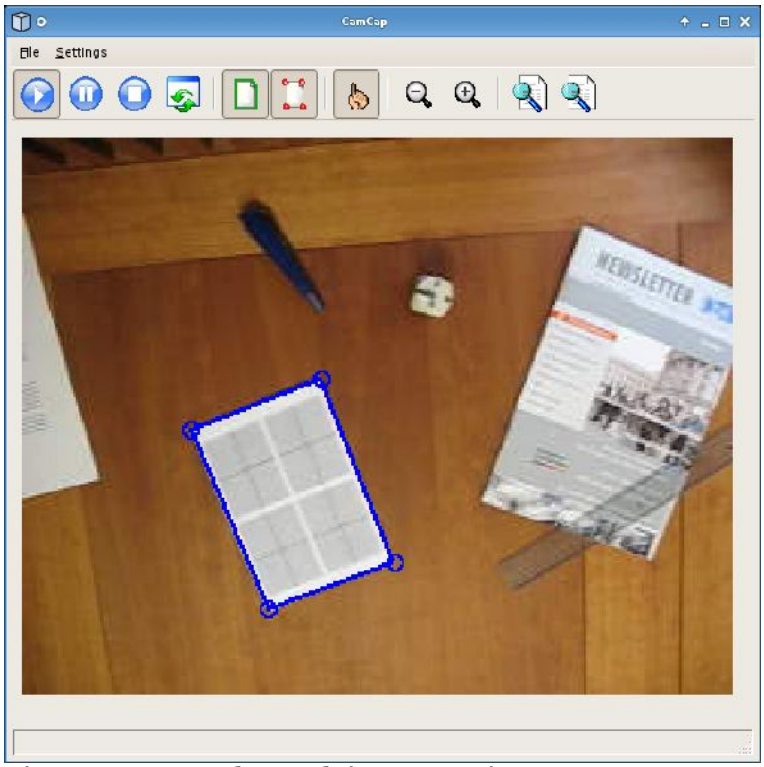


Figure 11: Interface of the second prototype

Also two new feedback elements were added. The first and most noticeable one being the audio feedback. Whenever the user points in a document the system will use a synthesized voice to tell the user to remove his hand from the document. The other feedback added to the systems consists of a drawing a blue cross in the document where the user pointed.

The colors around the document and fingertip also changed because users did not understand all the different colors in the first prototype. The meaning of the new colors around the document:

- Blue Document detected
- Red Capturing and processing the document
- Green Document captured and processed success

The new colors around the fingertip have the meaning:

- Blue Finger detected
- Green Pointing event occurred (after 2 seconds)

Not only the colors in the interface changed but also the internal document states changed. A user is now allowed point inside a document as soon as it is detected (colored blue), instead of having to wait for the document to turn orange. Another feature added to the application is the ability to point somewhere in a document that has already been captured. After this post-capture pointing event, the application will recapture the document.

The pointing mechanism also changed. By dropping a state were it would turn orange in the first prototype. Instead in now turn green after a finger has been stationary at a location for at least two seconds.

The results of these changes are discussed in the second user test (see Chapter 11).

11.Usability study II

Setup

To test whether the changes made improved the usability of the system another usability test was held. The same methods were used as in the first usability study only two questions regarding the audio feedback were added to the questionnaire:

The audio feedback was clear.	not at all						very much
The audio feedback was annoying.	not at all						very much

Again five (new) subjects were used for this usability test.

Results

Questionnaire

As in the first usability study all users noticed the different colors and were able to guess their representations.

Subjects tend to prefer the second type of interaction (the system waits for a pointing gesture infinitely), the one subject who preferred the first interaction mentioned that he only works with one document at the time.

The overall appreciation of the iDesk was higher than in the first usability study. The most striking result was that the quickness of the feedback was rated much higher, although this was not improved. However the response time (how quickly a finger/document is detected) was shorter. There are two explanations for this: either the users misinterpreted the question or the second group did not notice the delay because of the improved response time. The combined results of the questionnaire can be found in Appendix C.

Suggestions for which applications the subjects would like to use iDesk for were: Text editor, capturing images, image edit programs, capturing paragraphs.

Observations

1. The subjects switched their attention less than in the first usability test. If they did switch it mostly was because they were looking were they put the document. A possible explanation for the lower rate of switching between screen and desk is that the screen size has been increased. Now it is more clear to the users what they are doing. Although some subjects experienced difficulty understanding what the voice was actually saying.
2. The average learning curve was about 1 minute. Whenever the voice said to remove the hand from the document the subject responded accordingly. Also the subject did not need to wait until the rectangle around document turned orange. Which caused much confusion in the first usability test.
3. The subject rested their hand at the bottom of the desk or on their lap. This was outside the range of the viewfinder.
4. All but one subjects pointed and waited for feedback. This time the feedback was clear enough for the subjects to identify that the pointing gesture was finished.
5. This did not change for this usability study.
6. An error which also occurred in the first usability study was that subject tried to put the document back in the rectangle when the document was moved. Whenever a document is moved the rectangle indicating its position stays for a few frames.

Conclusions

From this usability test we can conclude that the second prototype improved the usability of the system. The overall appreciation of the iDesk was higher and the learning curve is reduced by a factor of 5. But there still are some improvements that can be made:

- Unintentional moving of the document should be detected.
- Improve the quality of the audio feedback (quality of the voice is poor)
- Delay of the rectangle around the document should be removed.

Further we can conclude that users very much like to use the system. Whether they also like to use it in practice is still to be learned. But the interaction using pointing gestures was very much appreciated.

12.Future work

Hand detection

Scale and rotation

The current hand detection uses multiple hand models to match possible hand blobs in the viewfinder. Implement a rotation and scale invariant matcher so they are not restricted to the size and orientation of the hand models.

Multiple hands and fingertips

Allow the matcher to find two hands in the viewfinder and detect multiple fingertips on each hand. This will allow advanced region selection and the use of gestures.

Document detection

Line detection

Improve the line detection algorithm by using RAST instead of Hough? The Hough transform seems to get somewhat unstable when multiple documents appear in the viewfinder.

Rectangle detection

The documents are found be finding any path over lines. Implement the algorithm used in [ZHA03] for more robust document detection.

Lines are sometimes broken into multiple smaller lines. Detect small lines that could form a single long line.

Region selection

Create region selecting in combination with multiple hand and fingertip detection. Or improve current one. Current region selection is that a second point is selected if there is at least a two second period between to pointing events. Just two crosses are drawn, maybe draw a rectangle in the correct perspective view of the document.

Multiple point events in a single document

This can be desirable if for example someone needs multiple images from a single document. By being able to first select all the images in the document before it is captured saves a lot of time because then the document does not need to be captured for every image.

13.Compilation Manual

The directory where this file is located is referenced to as the CamCap root directory or <ROOT>.

Needed files

This directory should contain:

- bin — Target directory for the compiled binary
- bin/handmodels — All images in this directory are used as hand models for matching
- bin/histograms — Histograms for Skin, Non-Skin and Table
- bin/histograms/non-skin-histogram
- bin/histograms/skin-histogram
- bin/histograms/table-histogram
- bin/icons — Icons used in the GUI
- bin/rectified — Directory where rectified documents are saved
- bin/autodetect.sh — Script to detect camera
- bin/run.sh — Script to start camcap
- libs — Directory with libraries (containts opencv-1.0 and libptp)
- libs/libptp2 — libptp2 directory
- obj — Directory to store object files during compilation
- src — Directory with source files
- Makefile — The makefile for CamCap
- README — Compilation manual

Required packages

The packages needed to compile and run camcap are:

- fftw3
- fftw3-dev
- flite1-dev
- libflite1
- libwxbase-2.6-0
- libwxbase-2.6-dev
- libwxgtk-2.6-0
- libwxgtk-2.6-dev
- libavcodec0d

- libformat0d
- libusb-0.1-4

Running CamCap

Run 'make' in the root directory of the camcap program. The source files (.cc and .h) should be in <ROOT>/src.

The compiled binary will end up in the <ROOT>/bin directory. CamCap can be started by executing run.sh in the bin-directory.

Run ./run.sh --help for all the camcap options.

14.User manual

This chapter presents the user manual on the additional functionality of the iDesk. The use of the document detection and pointing recognition is described. Also the additional functionality of the debug frames is described.

Document detection

Document detection is always turned on. Only when the pause button is pressed the iDesk does not process any frames, it just shows what the camera is capturing. A captured document is indicated in two ways:

- Rectangles around the documents
- Circles on the corner points of the documents

The different states of the the document detection is indicated by different colors:

- Blue: Document detected, you can point in the document.
- Red: Capturing document, please do not move or occlude the document.
- Green: Document captured.

You can put as many documents on the iDesk as long as they do not overlap. Whenever documents are detected badly or not at all reset the background using the background reset button.

Fingertip detection

Finger tip detection can be turned on and off by pressing the 'finger detection button'. When fingertip detection is turned on the iDesk captures documents after you pointed in it. When fingertip detection is turned of a document is captured immediately when it is detected.

A detected fingertip is represented by a circle. different colors indicate a different status:

- Blue: Location of the finger tip.
- Green: Pointing gesture recognized.

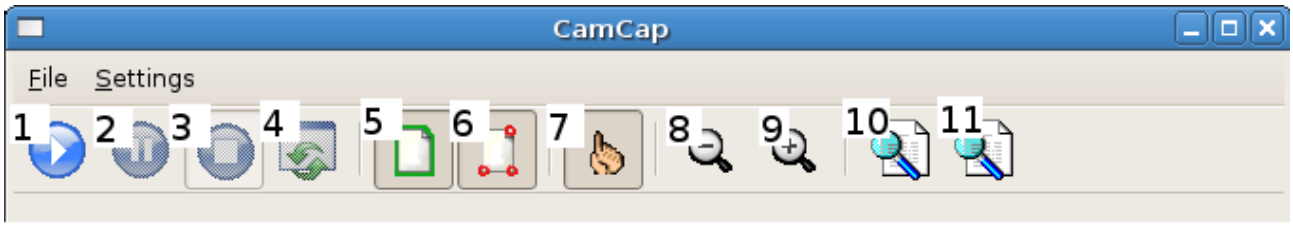
Whenever a pointing gesture is recognized a blue cross appears on that point. This indicates your pointed position. Also a voice will tell you that you should remove your hand. When you have removed your hand from the document it will be captured.

Captured documents

Captured documents are automatically rectified by the iDesk. Using the 'view captured documents' button you can see the documents that are captured and rectified. If you have pointed in the document a blue circle marks the area where you pointed.

Interface

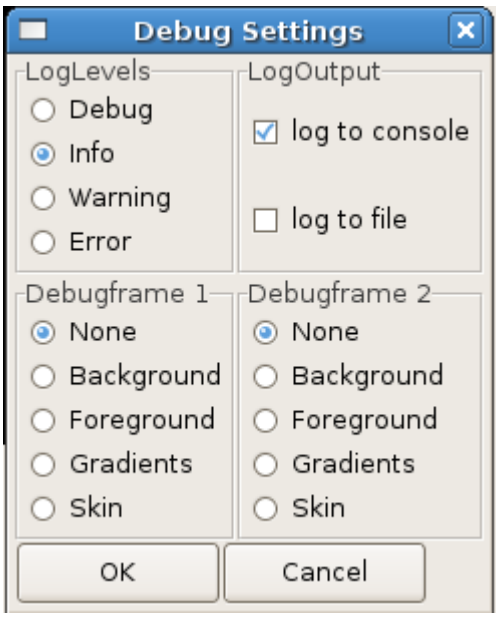
The functionality of the interface is as follows:



1. Start the iDesk
2. Pause the iDesk, captured frames are shown but not analyzed
3. Stop the iDesk
4. Reset background
5. Show borders around detected documents
6. Show corner points of detected documents.
7. Enable/disable finger detection.
8. Zoom out
9. Zoom in
10. Analyze documented (does nothing yet)
11. Show captured documents

There are two debug frames, the following debug modes can be selected .

- Background
- Foreground
- Gradients
- Skin



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Appendix A: Usability test iDesk

Introduction

The iDesk allows users to capture documents to their computer. When a document is placed on the desk it is detected and the document is captured. A new feature is gesture recognition, a user can point at a location in the document. These can be images that should be captured or an email address to which an email should be sent. This test consists of three parts with a questionnaire.

First test

For the first test we would like you to put a document on the desk and point at the image. The system should capture the document containing the image.

1. Press the play button in camcap: 
2. Put the document on the iDesk
3. Wait until a rectangle appears around the document.
4. Point at the image in the document, make sure that the document is captured.

Please do this test before reading further.

Which pointing gesture did you make?

1. Point and retract.
2. Point and wait for feedback.
3. Point and tap.
4. Other: .....

Did you see the different colors around the document and/or on the finger tip?

1. Yes
2. No

If you answered no in the last question, you can continue with the second test.

What do you think these colors mean?

Blue

around the rectangle :

.....

on the fingertip :

.....

Red

around the rectangle :

.....

Green

around the rectangle :

.....

on the fingertip :

.....

Did you understand what the voice said?

1. Yes
2. No

Before we start with the second test we first provide a short user manual.

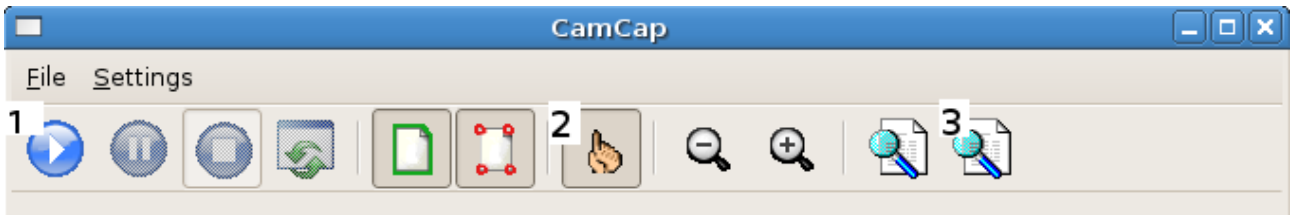
Short user manual

When you put a document on the iDesk a blue rectangle appears around the document. The iDesk will wait 10 seconds until it captures the document when it lays still, in this period you can point in the document. Capturing is defined by a red rectangle. When it is finished and the document is captured the rectangle turns green. If a document has been captured and you did not point in it yet you can still point in it afterwards. Then the document will be captured again.

When you make a pointing gesture you can see a blue circle at the location of your pointing finger. When your fingertip is at the same location for two seconds you have made a pointing gesture. This is indicated by the green circle on your fingertip. When your hand is removed from the document it will be captured.

The buttons needed for the tests are:

1. Start button: Starts the iDesk
2. Hand gesture toggle: Enables/Disables hand gesture recognition
3. Captured documents: Shows captured documents



Second test

For this test we would like you to do the following:

You should place two documents in the on the iDesk which both must be captured. Point at the image in one of the documents. You can either choose to put one document on the iDesk, point, and put the next document on the iDesk or put both documents on the iDesk and point in one. If the iDesk does not detect or capture the document properly you can (re)move the document and try again. Note that you can use the 'captured documents' button to see where you were pointing in the document.

Third test

This test is the same as the last test except for the interaction. The time limit of 10 seconds to point in the document is removed. Instead the iDesk waits until you point at a document and captures it afterwards.

Again put two documents on the desk and point at the image in one of these documents. Both documents need to be captured.

Questionaire

Age	
Male/Female	
Left/right handed	
Are you colorblind?	

1. Which interaction did you prefer? Test 2 / Test 3
2. Why?

   .....
3. The iDesk is:

hard to learn						easy to learn
inefficient						efficient
ineffective						effective
boring						fun

Was the feedback of the iDesk clear to you?	not at all						very much
Did you try to alter the position of the green circle when it appeared?	never						every time
Did you have any problems identifying the colors on the computer screen?	not at all						very much
How good could you identify the circle on your fingertip.	very poorly						very good
How good could you identify the rectangles around the documents	very poorly						very good
Were the representations of the colors clear to you?	not at all						very much
How often did you switch between looking at the computer screen and looking at the iDesk	never						all the time
How quick was the feedback of the iDesk.	slow						fast
Was the feedback quick enough?	not at all						very much
The audio feedback was clear.	not at all						very much
The audio feedback was annoying.	not at all						very much
Would you prefer to use a 'click gesture'?	not at all						very much

Did you like the idea of pointing in the document instead of using the mouse?	not at all						very much
The interaction with the iDesk felt natural/intuitive.	not at all						very much
Did you like to use the system?	not at all						very much
Do you think the iDesk is a useful system?	not at all						very much
Pointing gesures are a valuable addition to the iDesk.	not at all						very much

Which applications would you like to use the pointing recognition for (in the iDesk)?

.....

Any remarks/suggestions are welcome.

.....

.....

Appendix B: Questionnaire results of the first usability study

Age	28
Male/Female	5 M
Left/right handed	5 right
Are you colorblind?	5 no

1. Which interaction did you prefer? Test 2 / Test 3

   2 / 3

2. Why?

   .....

3. The iDesk is:

hard to learn		1		2	2	easy to learn
inefficient			2	3		efficient
ineffective			4	1		effective
boring					5	fun

Was the feedback of the iDesk clear to you?	not at all			2	3		very much
Did you try to alter the position of the green circle when it appeared?	never	2	1	1	1		every time
Did you have any problems identifying the colors on the computer screen?	not at all		2	1	2		very much
How good could you identify the circle on your fingertip.	very poorly				3	2	very good
How good could you identify the rectangles around the documents	very poorly				1	4	very good
Were the representations of the colors clear to you?	not at all	1		1	3		very much
How often did you switch between looking at the computer screen and looking at the iDesk	never		3		2		all the time
How quick was the feedback of the iDesk.	slow	1	3	1			fast
Was the feedback quick enough?	not at all	1	2	1	1		very much

Would you prefer to use a 'click gesture'?	not at all	1	1		1	2	very much
Did you like the idea of pointing in the document instead of using the mouse?	not at all				1	4	very much
The interaction with the iDesk felt natural/intuitive.	not at all		1	2	2		very much
Did you like to use the system?	not at all			1	1	3	very much
Do you think the iDesk is a useful system?	not at all			2	2	1	very much
Pointing gesures are a valuable addition to the iDesk.	not at all				3	2	very much

Which applications would you like to use the pointing recognition for (in the iDesk)?

.....

Any remarks/suggestions are welcome.

.....

.....

.....

Appendix C: Questionnaire results of the second usability study

Age	27
Male/Female	5 M
Left/right handed	5 right
Are you colorblind?	5 No

1. Which interaction did you prefer? Test 2 / Test 3

   1 / 4

2. Why?

   .....

3. The iDesk is:

hard to learn				3	2	easy to learn
inefficient			1	4		efficient
ineffective				3	2	effective
boring					5	fun

Was the feedback of the iDesk clear to you?	not at all			1	1	3	very much
Did you try to alter the position of the green circle when it appeared?	never	2	1	2			every time
Did you have any problems identifying the colors on the computer screen?	not at all	5					very much
How good could you identify the circle on your fingertip.	very poorly				1	4	very good
How good could you identify the rectangles around the documents	very poorly					5	very good
Were the representations of the colors clear to you?	not at all			1		4	very much
How often did you switch between looking at the computer screen and looking at the iDesk	never		3	1	1		all the time
How quick was the feedback of the iDesk.	slow			2	2	1	fast
Was the feedback quick enough?	not at all			2	2	1	very much

The audio feedback was clear.	not at all	2	1	1	1		very much
The audio feedback was annoying.	not at all	2	2	1			very much
Would you prefer to use a 'click gesture'?	not at all	1	2		1	1	very much
Did you like the idea of pointing in the document instead of using the mouse?	not at all			2	1	2	very much
The interaction with the iDesk felt natural/intuitive.	not at all			1	1	3	very much
Did you like to use the system?	not at all				1	3	very much
Do you think the iDesk is a useful system?	not at all			1	2	2	very much
Pointing gesures are a valuable addition to the iDesk.	not at all				4	1	very much

Which applications would you like to use the pointing recognition for (in the iDesk)?

.....

Any remarks/suggestions are welcome.

.....

.....

.....