Experimental Set 2:

It is a document contains colorful photos.

Fig5.32a, b, c, d, e:

They are the photo of whole document and its 4 sub-images which were taken under the guidance of GUI of "Take photos of the document".

(Resolution: 1600 x 1200 pixels each)

Fig5.33a, b, c, d, e:

The image of the whole document and its 4 sub-images after lens correction performed.

Fig5.34a: The high resolution image stitched from the sub-images after "Mark matching points of the photos manually" and "Stitch the photos".

(Resolution: 2400 x 3200 pixels each)

Fig5.34b: The resulting image after optimization of bilinear interpolation.

Fig5.34c: The resulting image after further optimized by thresholding, but it is an unnecessary process for this document. Reasons will be explained later.

Fig5.35: It is used to compare the original photo of whole document (*1600 x 1200 pixels*) and the resulting image (*2400 x 3200 pixels*) by showing 4 levels of details of the images.

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Fig5.32a A photo of the whole document.

Fig5.32b, c, d, e

The 4 sub-images of the document taken under the guidance of GUI.

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Fig5.33a Image of whole document after lens correction performed.

Fig5.33b, c, d, e

The 4 sub-images after lens correction performed.

GETTING AROUND

Got a Ticket to Ride

By HELEN GIBSON LONDON

...what was once East Berlin. Catch it at the zoo, and look for the bomb-damaged Kaiser Wilhelm Church tower, which stands as a reminder of the horrors of war. After passing the House of World Cultures, known by locals as the Pregnant Oyster, the bus approaches the Reichstag. It sports a huge glass dome by British architect Norman Foster that sits over the plenary hall—from the viewing deck inside you can look down and see parliamentarians at work. Just behind the Reichstag, look carefully for the cobblestone line marking where the Wall once stood. Passing the Brandenburg Gate, you travel on Unter den Linden boulevard with its elegant 18th century buildings, which contrast sharply with the stark East bloc architecture of Alexanderplatz, the final stop. Cost: single ticket $2.55, full-day ticket $7.00. Journey time: about 30 minutes.

square b... on the ... open space left by a 1755 ... and tsunami. Then, ... climbed up the smart ... district with its old co... shops, the tram ... through the 17th century str... of the Bai... Alto. Before ... the ... Bento parli... building, you pass the Bi..., a deep cleft in the hillside left by the earthquake. It now houses one of Lisbon's funiculars. End of the line is the Prazeres Cemetery, with tombs in every possible architectural style. Cost: $1.50 one-way, $1.80 round trip. Journey time: about 40 minutes.

LONDON: Catch a westbound No. 11 bus at the Bank of England in the City financial district and make for the top deck to enjoy a bird's eye view of St. Paul's Cathedral, Big Ben and Westminster Abbey. Moving down Whitehall, after passing the two Queen's Household Cavalry sentries outside Horse Guards Parade, the bus approaches the iron gates that guard the entrance to 10 Downing Street—you might catch a glimpse of the Prime Minister addressing the press pack outside his famous front door. Another bonus: a ride on Chelsea's trendy King's Road before reaching the last stop in Fulham. Cost: $2.60. Journey time: about 60 minutes.

PARIS: The No. 69 bus takes you along the Seine from the Eiffel Tower to the historic Marais district. After sampling the sights of the Boulevard St. Germain, one of the world's most elegant shopping streets, enjoy the Marais' narrow streets and renovated mansions, much in vogue now among the Parisian in crowd. In the Rue des Rosiers, sample some of the capital's best Jewish food. Cost: $1.70. Journey time: about 30 minutes.

ROME: Take Linea 3 (normally a tram route but partially serviced by a bus until the fall) from Trastevere for a tour of ancient Rome and neighborhoods ranging from Testaccio, featuring some of the capital's hottest restaurants, to the wealthy oleander-treelined neighborhood of Parioli near the Villa Borghese Park, and the San Lorenzo quarter, where the streets hum with university student life. You'll cross the Tiber by the Sublicio Bridge. Before reaching the final stop near the National Gallery of Modern Art, the route passes such landmarks as the Colosseum, the ancient church of Santa Croce in Gerusalemme, and the 1st century pyramid built as a tomb by a magistrate with dreams of grandeur. Cost: $1.20. Journey time: about 45 minutes. —*With reporting by Martha de la Cal/Lisbon, Julia Mason/Paris, Mimi Murphy/Rome and Regine Wosnitza/Berlin*

CLOCKWISE FROM BOTTOM LEFT: REGIS BOSSU—SYGMA/CORBIS; RAINER JAHNS; PICTORIAL PRESS/ALAMY; ROCHAPHOTO/ALAMY;

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Fig5.34a The high resolution image stitched from the sub-images.

TIME GLOBAL ADVISER

GETTING AROUND

Got a Ticket to Ride

Organized tours not your style? Jump on the best of Europe's local buses and trams

By HELEN GIBSON LONDON

YOU'RE VISITING A EUROPEAN capital and you'd like to take in some of the sights. But you're not so keen on shelling out for an expensive tourist bus to be assailed by a loud commentary. So why not try public transport? It's cheap, it's fun to sit among the locals, and certain bus and tram routes are so scenic they could have been set specifically with sightseers in mind. Here's a roundup of the best routes:

BERLIN: Journey through recent German history on the No. 100 double-decker bus as it crosses from the former West Berlin to what was once East Berlin. Catch it at the zoo, and look for the bomb-damaged Kaiser Wilhelm Church tower, which stands as a reminder of the horrors of war. After passing the House of World Cultures, known by locals as the Pregnant Oyster, the bus approaches the Reichstag. It sports a huge glass dome by British architect Norman Foster that sits over the plenary hall—from the viewing deck inside you can look down and see parliamentarians at work. Just behind the Reichstag, look carefully for the cobblestone line marking where the Wall once stood. Passing the Brandenburg Gate, you travel on Unter den Linden boulevard with its elegant 18th century buildings, which contrast sharply with the stark East bloc architecture of Alexanderplatz, the final stop. Cost: single ticket $2.55, full-day ticket $7.00. Journey time: about 30 minutes.

LISBON: Pick up the No. 28 tram at Largo da Graça, above the imposing São Jorge Castle, with the destination "Prazeres" on the front. After clattering around the hilly, twisting streets of medieval Alfama at sometimes breakneck speeds, you'll reach the calm of the 18th century Baixa Pombalina district on the banks of the Tagus River. Through the Rua Augusta arch you see Praça do Comercio, the colonnaded square built on the vast open space left by a 1755 earthquake and tsunami. Then, having climbed up the smart Chiado district with its old coffee shops, the tram clangs through the 17th century streets of the Bairro Alto. Before reaching the São Bento parliament building, you pass the Bica, a deep cleft in the hillside left by the earthquake. It now houses one of Lisbon's funiculars. End of the line is the Prazeres Cemetery, with tombs in every possible architectural style. Cost: $1.50 one-way, $1.80 round trip. Journey time: about 40 minutes.

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Fig5.34b The resulting image after optimization of bilinear interpolation

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BERLIN: Journey through recent German history on the No. 100 double-decker bus as it crosses from the former West Berlin to what was once East Berlin. [illegible] at the zoo, and look for the bomb-damaged Kaiser Wilhalm Church tower, which stands as a reminder of the horrors of war. After passing the House of World Cultures, known by locals as the Pregnant Oyster, the bus approaches the Reichstag. It sports a huge glass dome by British architect Norman Foster that sits over the plenary hall—from the viewing deck inside you can look down and see parliamentarians at work. Just behind the Reichstag, look carefully for the cobblestone line marking where the Wall once stood. Passing the Brandenburg Gate, you travel on Unter den Linden boulevard with its elegant 18th century buildings, which contrast sharply with the stark East bloc architecture of Alexanderplatz, the final stop. Cost: single ticket $2.55, full-day ticket $7.00. Journey time: about 30 minutes.

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CLOCKWISE FROM BOTTOM LEFT: REGIS BOSSU—SYGMA/CORBIS; RAINER JAHNS; PICTORIAL PRESS/ALAMY; [illegible] IMAGESTATE/ALAMY

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Fig5.34c The resulting image after optimization of thresholding

Fig5.35 Comparison of the original photo and the resulting image

Fault rate:

We simply define the fault rate as:

$$\text{Fault Rate} = \frac{\text{Number of grids contains obvious defects}}{\text{Total number of grids (100)}}$$

This percentage value shows how much defects exist such that the words or pictures are missed or unclear.

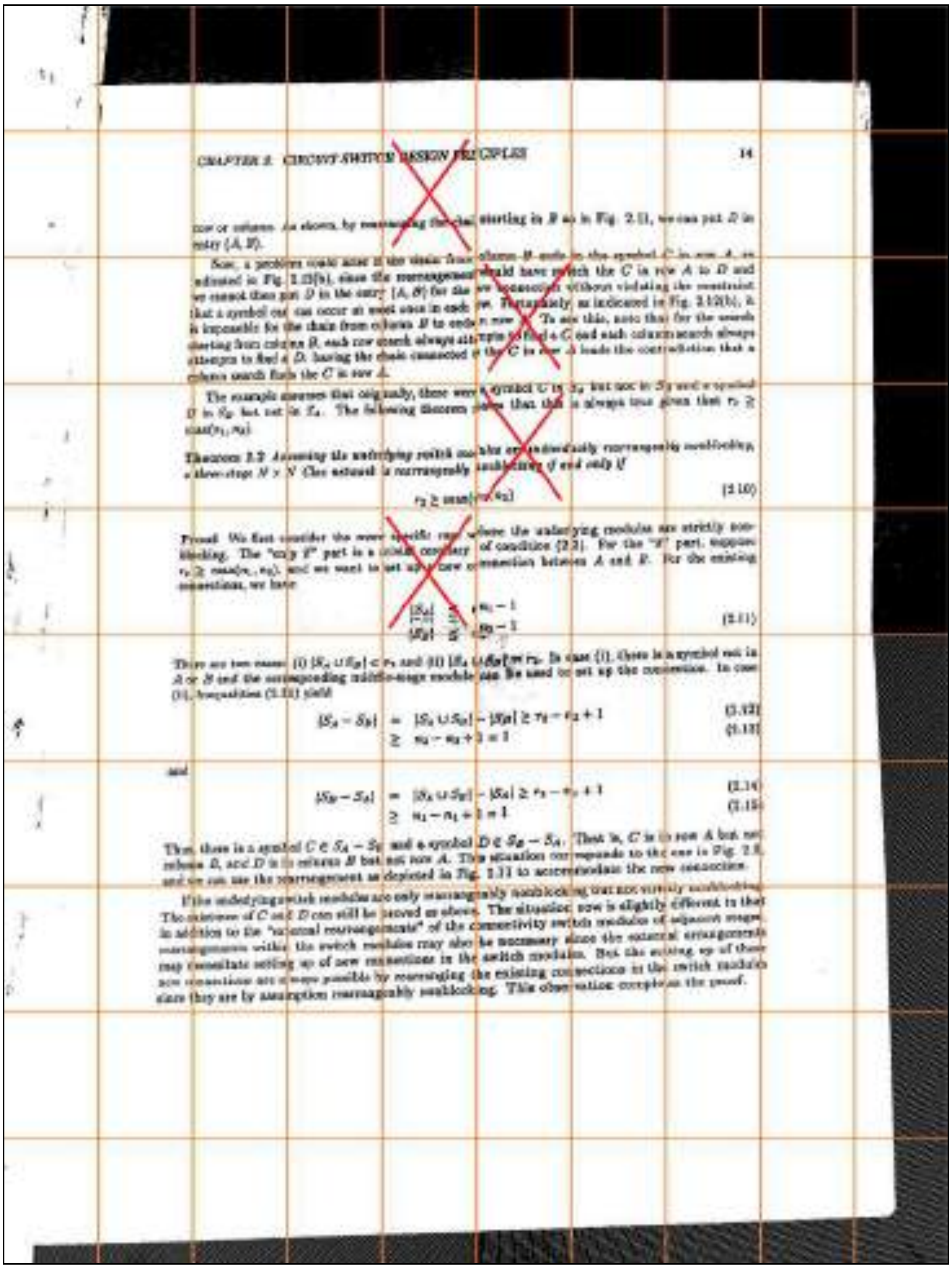


Fig5.36a Result of Experimental Set 1

Fig5.36b Result of Experimental Set 2

Fault Rate of Experimental Set 1 = 4 / 100

= 4 %

Fault Rate of Experimental Set 2 = 7 / 100

= 7 %

5.8 Conclusion

Explanation of the results:

1. By the comparison of Fig5.27a and Fig5.28a, Fig5.32a and Fig5.33a, we can find that the edge of the document follows a straight line after lens correction performed. It is also clearly shown in Fig5.29. These shows that lens correction has satisfactory results.

2. For a document containing words only, even after bilinear interpolation is performed, the result is not the optimal case (Fig5.30b). Although the words can be recognized, combination of different regions looks strange. Therefore we can further enhance the result by carrying out thresholding (Fig5.30c). Words became solid black and the background color became white, thus this high contrast gives a better looking of the resulting image.

3. For a document containing colorful pictures inside, thresholding is an unnecessary process because the details of the picture are not able to retain (Fig5.34c). Thus Fig5.34b is a better result for such kind of document, but this restriction does not apply to documents containing only black and white pictures.

4. A special case is shown in Fig5.34b and Fig5.34c. Regardless of the picture in the middle, thresholding made some of the words in Fig5.34c disappeared in which those words can be found in Fig5.34b. This is due to overexposure as the paper is reflecting light unevenly. We can observe this in Fig5.32d. Therefore the threshold value of thresholding false

recognized those parts as white (containing no words).

5. We can see obviously from Fig5.31 and Fig5.35 that, the resolution of a high-end mobile camera (*2 Megapixels*) is still not enough for capturing a whole document. The words are blurred and unclear (Upper half of Fig5.31 & Fig5.35). But after using our system, details of documents are retained and the words have sharp edges (Lower half of Fig5.31 & Fig5.35). It is suitable for sending the document out by fax as their low fault rates.

6. There are still defects after optimizations (Fig5.37). They are sometimes found at the boundaries where the sub-images combined. There is no trivial method to avoid them and seems there are still no commercial products that can have perfect result.

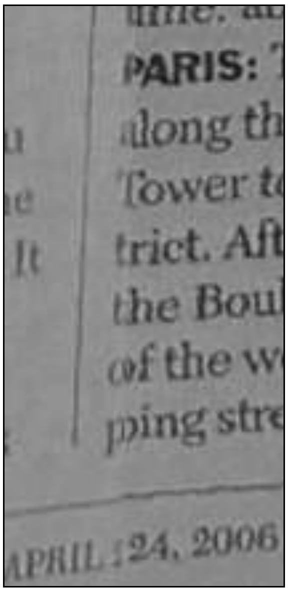
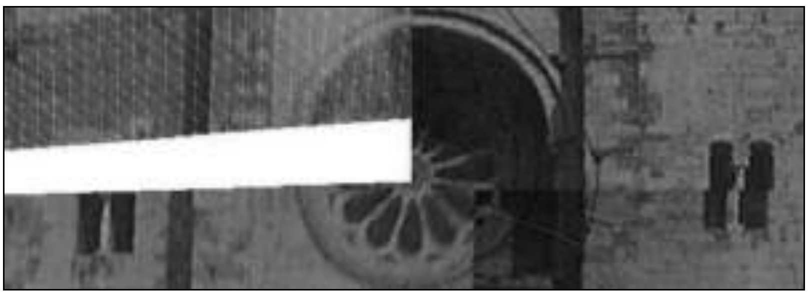


Fig5.37 Some defects found in Fig5.34b



Advantages of our system:

- Stitch through any direction
  - Traditional panorama stitch only horizontal or vertical consecutive images. But the direction for stitching in our project is not limited, any direction is possible.

- Stitch images of different scales
  - When taking photos for any part of the document, the distance between the document and the camera is not important. Users just need to ensure the focusing is correct.

- Stitch images of different orientation
  - Users can take photos in any angles, the document image can still be recovered after stitching.

- Optimize for black and white documents
  - Since for a normal fax document, it is most likely a black and white document, our system can optimize to make the high resolution image sharper.

Chapter 6 Project Progress

Here is our progress of the final year project.

June, 2005 To August, 2005	1. Familiar with digital image processing 2. Familiar with development platform of Symbian OS.
Sep, 2005	1. Try the sample program of Symbian OS. 2. Thinking FYP topic
October, 2005	1. FYP topic decided. 2. Try to implement program to access image raw data on Symbian phone using related API. 3. Try to implement program to decode and encode image on Symbian phone using related API. 4. Try to implement program to facsimile things on Symbian phone using related API. 5. Study concept of image alignment and stitching (mainly focus on direct method). 6. Find sample code of SIFT (extract and match keypoints).
November, 2005	1. Study concept of image alignment and stitching (mainly focus on SIFT). 2. Study sample code of SIFT. 3. Make use of the sample code of SIFT. 4. Implement geometric transformation to transform images and merge the document on PC. 5. Prepare 1st term project presentation and demonstration. 6. Writing 1st term FYP report

December, 2005	1. Try implement SIFT on Symbian phone.
January, 2006	1. Find out that SIFT is not suitable on Symbian phone. 2. Try to find other to solve the problems.
February, 2006	1. Design the user interface on Symbian phone. 2. Implement overlaying on PC. 3. Implement the user interface to take photo.
March, 2006	1. Implement overlaying on Symbian phone. 2. Implement the user interface to mark points manually. 3. Implement lens correction on Symbian phone.
April, 2006	1. Implement the photo stitching on Symbian phone. 2. Implement the photo optimization on Symbian phone. 3. Prepare 2nd term project presentation and demonstration. 4. Writing 2nd term FYP report

Chapter 7 Difficulties

7.1 Limited speed of Symbian phone

Our project mainly involves image processing, especially image alignment and transformation. Image alignment involves a of search work. Image transformation involves editing of image data. These works need some time to process even on personal computer. As a result, we need to optimize it as much as possible or make use of more efficient so that it can be run on Symbian phone.

In addition, we need to make some assumption of our project in order to make it efficient. At this stage, we assume that the image of document is planer and it is a black and white photo.

7.2 Limited memory of Symbian phone

The images we use to process are 2 Mega pixel photos. As a result, memory usage is also one of our concerns. Unlike personal computer, the Symbian phone would not have much memory. It does not have large memory space and virtual memory for our working space. We need to make careful use of memory. Otherwise, the program cannot be run on Symbian phone.

7.3 Difficult to debug

Each time the program has been compiled. The program is then transferred to the Symbian phone and installed in it. Then the program can run be on the Symbian phone. It may take some time to run. When the program terminates abnormally, it is different to track out where does it happens as there is no debugger and it is not possible to print out some data easily. Although there is an emulator on PC, it is not reliable. Program can be run on the emulator does not necessarily means that it can be run on Symbian phones. Actually, the result from the emulator may be sometimes different from that from Symbian phones

7.4 Lack of clear documentation for fax API

So far, I still cannot implement faxing on Symbian phone. One of reason is that there is no clear documentation of faxing API. The documentation of SDK tool just states about the usage of the related object and its function.

In addition, a class related to faxing API has been deleted in the new version of Symbian OS. Originally, two faxing related API is found. Now there is only one left. And it seems this one is more difficult to use.

7.5 Unfamiliar with digital image processing

Before the FYP, both of us do not have any knowledge of image processing. As a result, when we studied the concept of image alignment and stitching, we need to spend much more time to study the basic concepts and notations of digital image processing.

Fig7.1 Difficulties encountered cartoon

Chapter 8 Contribution of work

8.1 Introduction:

In the following, I would describe my contribution of work in the final year project. I would divide my contribution into two main stages: preparation stage and implementation stage. Preparation stage is mainly done in the summer and the beginning of the first semester. Implementation stage is mainly done in the end of the first semester and the second semester.

8.2 Preparation stage

In this stage, I have spent much time on it as I had no idea on both Symbian OS and image processing before the project.

8.2.1 Familiar with Symbian API

In the summer, I started to learn what Symbian OS is and how to work with development platform for Symbian OS. During the learning, I had tried the sample code provided in the SDK tool. Beside, I had also ported a program, which originally runs on PC, to Symbian phone. The program is about video decoding and encoding with codec of H.263. Although the quality of the video produced by the program on Symbian phone was not good, I got familiar with the development platform of Symbian OS.

8.2.1 Learning of image alignment and stitching

After the objective has been decided, I started to study image alignment and stitching together with my partner. As I did not have any experience of image processing before, much time is spent on it.

During studying, I first came across the direct method of image alignment. Then when we knew the existence of SIFT and its sample code, we changed to study the feature base registration as SIFT can extract stable keypoints. Both of us thought that feature base registration was suitable for our project. At the same time, my partner tried to make use of the sample code and I study the theory of SIFT to give support to my partner.

8.2.2 Testing of Symbian API

Apart from studying of image alignment and stitching, I tried to implement related functions on the Symbian phone. The related function included how to access and modify raw data of image, how to decode and encode image to specified formats like JPEG, how to take photo using the onboard camera and how to do faxing. The Symbian SDK provides related API for all of them. Apart from faxing, I successfully implemented program to use the functions. However, I still could not implement faxing function. The main reason was that the documentation of the SDK did not provide enough information for me.

8.3 Implementation stage

After we had implemented the stitching on PC, I tried to port the program to the Symbian phone directly. However, I found that it could not be done because the sample code of SIFT was too complex and it was written in C# where C++ is the native language of Symbian OS. Instead, we planned to implement SIFT ourselves with reference to the sample code.

8.3.1 Implement of SIFT on Symbian phone

I have implemented some parts of the SIFT myself. That was detecting extrema in scale-space and keypoint localization. However, we discovered that finding and matching points using SIFT needed much time to process even on PC. As a result, we decided to give up using SIFT on Symbian phone and try to find another method to substitute this part.

8.3.2 Implementation of taking photos on Symbian phone

After the interface of taking photos on Symbian phone had been designed, I implemented this part of our project. Firstly, I studied how to do overlaying and wrote a program to overlay two still images on PC. Then I implemented application on Symbian phone to overlay one still image and the current frame from the camera. At that moment, I could make use of techniques which are tested previously. These techniques include how to access and modify raw data of image, how to get the current frame and etc. After the application is implemented, I could test if overlaying could be done on Symbian phone efficiently.

Finally, I modified the program and successfully implemented taking photos on Symbian phone, which is our first part of our program.

8.3.3 Porting of lens correction on Symbian phone

As lens correction was implemented on PC, I ported lens correction to Symbian phone. The code is written in Matlab originally. I tried to rewrite it in Symbian C++ and it works properly.

8.3.4 Implementation of manually marking matching points on Symbian phone

We had given up to use SIFT in our project. Instead, we planned to ask the user to mark matching points manually. The major issues involved are how to display correct image in the screen and ask for user input. As I had already had quite a lot of experience of developing Symbian application, I implemented this part without facing many technical problems as before.

8.4 Conclusion

In the final year project, I had learnt many things. I studied much knowledge about image processing, particular for image alignment and stitching and SIFT. Furthermore, I had gained excellent experience to develop application program for Symbian phone. Resources like memory should be handled very carefully when developing application for Symbian phone.

Apart from technical knowledge, the experience in the final year project taught me other things. For example, I learnt how to make decision and how important teamwork is.

Chapter 9 Conclusion

In this project, we have studied a lot of image alignment and stitching algorithms, and implemented them on both PC and Symbian platforms. Through the implementation and testing, we learned the windows programming development environment and Symbian programming development environment.

The major difficulties we faced are the balance between accuracy and speed of alignment and stitching. In order to stitch and form a high-resolution sharp document image, we need to align the images correctly. More number of much detailed keypoints recorded, higher the chance to match the correct keypoints. However, the time taken is directly proportion to the number and details of keypoints recorded. Therefore, it is hard to get the balance.

We proposed a new method of stitching and our system has several advantages over traditional panorama. Images of different orientations and scales can still be stitched correctly. Moreover, we have an optional blending optimization for making high resolution black and white documents.

Last but not the least, although our system is focusing on reconstruction of document images, documents that contain images or photographs are possible to stitch using our system.

Chapter 10 Further Improvements

10.1 Optimization for Symbian Platform

Considering the processing power of mobile phones and the specialty of Symbian Platform, we encountered restrictions than writing program for PC. For example, mobile phones are weak at floating point operations. Thus in order to make our program to run faster on mobile phones, we have to modify our program so that most of the operations are integral operations instead of floating point operations. However, the program we implemented at this stage does not have extra handling for this concern.

10.2 Restoration based on video

In our project, image alignment plays an important role. Thus if more constraints are given for matching the feature points, higher the accuracy can be achieved. Since the nature of video frames is basically a consecutive sequence of images, we may be able to use this nature to establish constraints in image alignment. In other words, our product may allow user to capture the document in a video clip and carry out restoration based on that video clip. However, there may be a trade off of quality and accuracy. Although image alignment may become more accurate if constraints are added, quality of video clips on mobile phones are still a concern.

10.3 Automatic lens correction

Since the lens distortions are different for different camera lens, an automatic lens correction can adapts to the circumstance and gives better results. It is found that in 1999, Mr Harri Ojanen already showed that even with inexpensive zoom lenses, near perfect images can be obtained by using a correction algorithm based on a simple mathematical model and without any special measuring tools. Therefore, it should be possible to make automatic lens correction available in our product to adapt to any models of mobile phones.

10.4 A better blending technique

In our project, sharpness of the image is the most important thing that we concern. At present, we have used bilinear interpolation and averaging mask to blend the final image, so that fewer defects can be seen on the merging boundaries. However, there are still rooms for improvement. Technique of super resolution is one of the ways to increase sharpness and details of digital images. But the choice of algorithms or techniques are still be restricted by the processing power and memory of phone models.

Chapter 11 Acknowledgement

We would like to express our thank to our final year project superviser, Professor Michael R. Lyu. He has given us many suggestions and provided equipments throughout the project.

We would like to think Mr. Edward Yau, who gave us a lot of innovative idea and suggestion for our project.

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