# Digital Image Processing编程作业

学生姓名： 许一宁 学号： 2018222050154

### 第一章

编程1：编程将一幅图像降质为多个低空间分辨率图像

##### 源代码及重点语句的注释

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| --- |
| void CImage\_ProcessingView::OnResolution(){  // TODO: 在此添加命令处理程序代码  if (m\_Image.IsNull()) return;//判断图像是否为空，对空图像操作会出现未知的错误  int w = m\_Image.GetWidth();//获得图像的宽度  int h = m\_Image.GetHeight();//获得图像的高度  int bits = m\_Image.GetBPP();  int C = 3;  int inter = 5; //降低图像五倍分辨率  for (int c = 0; c < C; c++){  for (int j = 0; j < h; j++){  for (int k = 0; k < w; k++){  m\_Image.m\_pBits[c][j][k] = m\_Image.m\_pBits[c][j / inter \* inter][k / inter \* inter];  }  }  }  Invalidate(1); //强制调用ONDRAW函数，ONDRAW会绘制图像  } |

##### 实现结果展示

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| 原图 | 降低分辨率后的图 |

编程2：编程将一幅256级的灰度图像分解为不同灰度分辨率（128、64、32、16、8、4、2）的图像。

##### 源代码及重点语句的注释

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| void CImage\_ProcessingView::OnGraychange(){  // TODO: 在此添加命令处理程序代码  if (m\_Image.IsNull()) return;//判断图像是否为空，空图像进行操作会出现未知的错误  int w = m\_Image.GetWidth();//获得图像的宽度  int h = m\_Image.GetHeight();//获得图像的高度  int bits = m\_Image.GetBPP();  int hierarchical = 2;  for (int j = 0; j < h; j++){  for (int k = 0; k < w; k++){  int ave = 0.1140 \*m\_Image.m\_pBits[0][j][k] + 0.5870 \*m\_Image.m\_pBits[1][j][k] + 0.2989 \*m\_Image.m\_pBits[2][j][k]; // change image to gray  m\_Image.m\_pBits[0][j][k] = ave;  m\_Image.m\_pBits[1][j][k] = ave;  m\_Image.m\_pBits[2][j][k] = ave;  }  }  int K = 2; //灰度分辨率等级  for (int i = 0; i < h; i++){  for (int j = 0; j < w; j++){  int step = 256 / (K); //计算等级跨度  int value = (step << 1) - 1;  m\_Image.m\_pBits[0][i][j] = (m\_Image.m\_pBits[0][i][j] / step) \* value;  m\_Image.m\_pBits[1][i][j] = (m\_Image.m\_pBits[1][i][j] / step) \* value;  m\_Image.m\_pBits[2][i][j] = (m\_Image.m\_pBits[2][i][j] / step) \* value;  }  }  Invalidate(1); //强制调用ONDRAW函数，ONDRAW会绘制图像  } |

##### 实现结果展示

以下为原图以及分辨率依次为128,64,32,16,8,4,2。

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编程3：编程实现图像差分、多幅图像相加去噪。

##### 流程图

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| 图片差分流程图 | 图片叠加去噪流程图 |

##### 源代码及重点语句的注释

1、图片差分

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| void CImage\_ProcessingView::OnDiff(){  // TODO: 在此添加命令处理程序代码  if (m\_Image.IsNull()) return;//判断图像是否为空，对空图像操作会出现未知的错误  int w = m\_Image.GetWidth();//获得图像的宽度  int h = m\_Image.GetHeight();//获得图像的高度  int bits = m\_Image.GetBPP();  int hierarchical = 2;  MyImage\_ m\_Image2;  CFileDialog dlg(TRUE);//同样是打开一个新的对话框，存储别的输入图片  if (IDOK == dlg.DoModal()){  if (!m\_Image2.IsNull())  m\_Image2.Destroy();  m\_Image2.Load(dlg.GetPathName());  if (m\_Image2.IsNull())  return;  int w0 = m\_Image2.GetWidth();  int h0 = m\_Image2.GetHeight();  if (w0 != w || h0 != h) return;//比较两张图片大小，如果不同就return  for (int i = 0; i < h; i++){  for (int j = 0; j < w; j++){  m\_Image.m\_pBits[0][i][j] = m\_Image.m\_pBits[0][i][j] - m\_Image2.m\_pBits[0][i][j];  m\_Image.m\_pBits[1][i][j] = m\_Image.m\_pBits[1][i][j] - m\_Image2.m\_pBits[1][i][j];  m\_Image.m\_pBits[2][i][j] = m\_Image.m\_pBits[2][i][j] - m\_Image2.m\_pBits[2][i][j]; //逐像素计算差值  }  }  Invalidate(1);  }  } |

2、叠加去燥

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| void CImage\_ProcessingView::OnDenoiseing(){  // TODO: 在此添加命令处理程序代码  if (m\_Image.IsNull()) return;//判断图像是否为空，对空图像操作会出现未知的错误  int w = m\_Image.GetWidth();//获得图像的宽度  int h = m\_Image.GetHeight();//获得图像的高度  int bits = m\_Image.GetBPP();  int hierarchical = 2;  MyImage\_ m\_Image2;  CFileDialog dlg(TRUE);//同样是打开一个新的对话框，存储别的输入图片  dlg.m\_ofn.Flags |= OFN\_ALLOWMULTISELECT;//允许选择多个文件  dlg.m\_ofn.nMaxFile = 20 \* 101;//最多可以打开20个文件，每个文件名的字符数<=100  const DWORD numberOfFileNames = 32;//最多允许32个文件  const DWORD fileNameMaxLength = MAX\_PATH + 1;  const DWORD bufferSize = (numberOfFileNames \* fileNameMaxLength) + 1;  TCHAR\* filenamesBuffer = new TCHAR[bufferSize];  filenamesBuffer[0] = NULL;//必须的  filenamesBuffer[bufferSize - 1] = NULL;  dlg.m\_ofn.lpstrFile = filenamesBuffer;  dlg.m\_ofn.nMaxFile = bufferSize;  CStringArray strArrFilePaths;  if (dlg.DoModal() == IDOK){  int k = 0;  POSITION pos = dlg.GetStartPosition();//获取第一个文件名的位置  while (pos != NULL) //GetNextPathName()返回当前pos的文件名，并将下一个文件名的位置保存到pos中，最后达到连续叠加多幅图片{  if (!m\_Image2.IsNull())  m\_Image2.Destroy();  m\_Image2.Load(dlg.GetNextPathName(pos));  if (m\_Image2.IsNull())return;  for (int i = 0; i < h; i++){  for (int j = 0; j < w; j++){  m\_Image.m\_pBits[0][i][j] = (m\_Image.m\_pBits[0][i][j] / (k + 2))\*(k + 1) + m\_Image2.m\_pBits[0][i][j] / (k + 2);  m\_Image.m\_pBits[1][i][j] = (m\_Image.m\_pBits[1][i][j] / (k + 2))\*(k + 1) + m\_Image2.m\_pBits[1][i][j] / (k + 2);  m\_Image.m\_pBits[2][i][j] = (m\_Image.m\_pBits[2][i][j] / (k + 2))\*(k + 1) + m\_Image2.m\_pBits[2][i][j] / (k + 2); //计算叠加图片的数量并继续叠加。  }  }  k++;  }  Invalidate(1);  }  } |

##### 实现结果展示

1. 差分结果图

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| 原图 | 相减图像 |
| 差分后图像 | |

2、叠加去噪结果图。

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| 加入噪声后的图片 | 叠加去噪后的效果 |

### 第三章

编程1：编写程序统计任意一幅图像的直方图并显示

##### 源代码及重点语句的注释

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| --- |
| void CImage\_ProcessingView::OnHistogram(){  // TODO: 在此添加命令处理程序代码  if (m\_Image.IsNull()) return;//判断图像是否为空，对空图像操作会出现未知的错误  int w = m\_Image.GetWidth();//获得图像的宽度  int h = m\_Image.GetHeight();//获得图像的高度  int bits = m\_Image.GetBPP();  int hierarchical = 2;  if (bits == 24 || bits == 32) {  for (int i = 0; i < h; i++){  for (int j = 0; j < w; j++){  int ave = 0.1140 \*m\_Image.m\_pBits[0][i][j] + 0.5870 \*m\_Image.m\_pBits[1][i][j] + 0.2989 \*m\_Image.m\_pBits[2][i][j];  m\_Image.m\_pBits[0][i][j] = ave;  m\_Image.m\_pBits[1][i][j] = ave;  m\_Image.m\_pBits[2][i][j] = ave;  }  }  }  m\_Image.calcHistogram();//调用m\_Image内的直方图统计函数  paintHistDialog dlg(this);//用一个CImage\_ProcessingView的指针取初始化dlg  dlg.DoModal();  Invalidate(1);  }  //直方图统计函数  void MyImage\_::calcHistogram(void)//直方图统计{  BYTE \*lpSrc; //指向源图的指针  int w = GetWidth();  int h = GetHeight();  int arr[256] = {0}; //每个灰度值统计  int nrow = m\_CImage.GetPitch();//获得Image每一行像素的RGB所占用的存储空间的大小  for (int i = 0; i < h; i++){  for (int j = 0; j < w; j++){  BYTE value = m\_pBits[0][i][j];  arr[value] ++;  }  }  for (int k = 0; k < 256; k++){  hist[k] = arr[k] / (w\*h\*1.0f); //Normalization  }  } |

##### 实现结果展示

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原图 归一化直方图

编程2：编程实现图像均衡化和图像规格化

##### 流程图

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| 直方图均衡流程图 | 直方图匹配流程图 |

##### 源代码及重点语句的注释

1、直方图均衡

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| void CImage\_ProcessingView::OnHistequal(){  // TODO: 在此添加命令处理程序代码  if (m\_Image.IsNull()) return;//判断图像是否为空，对空图像操作会出现未知的错误  int w = m\_Image.GetWidth();//获得图像的宽度  int h = m\_Image.GetHeight();//获得图像的高度  int bits = m\_Image.GetBPP();  int hierarchical = 2;  if (bits == 24 || bits == 32) {  for (int i = 0; i < h; i++){  for (int j = 0; j < w; j++){  int ave = 0.1140 \*m\_Image.m\_pBits[0][i][j] + 0.5870 \*m\_Image.m\_pBits[1][i][j] + 0.2989 \*m\_Image.m\_pBits[2][i][j];  m\_Image.m\_pBits[0][i][j] = ave; // change image to gray  m\_Image.m\_pBits[1][i][j] = ave;  m\_Image.m\_pBits[2][i][j] = ave;  }  }  }  m\_Image.calcHistogram();  float s[256] = { 0 };//均衡  int hist\_equal[256] = { 0 };//均衡后  for (int i = 0; i < 256; i++){  for (int j = 0; j <= i; j++){  s[i] += 255 \* m\_Image.hist[j]; //建立均衡后的映射关系  }  hist\_equal[i] = floor(s[i]); // 对映射关系去下整数  }  for (int i = 0; i < h; i++){  for (int j = 0; j < w; j++){  int value = m\_Image.m\_pBits[0][i][j];  int new\_value = hist\_equal[value]; //利用映射关系对图片像素进行操作  m\_Image.m\_pBits[0][i][j] = new\_value;  m\_Image.m\_pBits[1][i][j] = new\_value;  m\_Image.m\_pBits[2][i][j] = new\_value;  }  }  m\_Image.calcHistogram();  paintHistDialog dlg(this);//用一个CImage\_ProcessingView的指针取初始化dlg  dlg.DoModal();  Invalidate(1);  } |

1. 直方图规定

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| void CImage\_ProcessingView::OnHistmatch(){  // TODO: 在此添加命令处理程序代码  MyImage\_ m\_Image\_Match;  CFileDialog dlg(TRUE);//同样是打开一个新的对话框，存储别的输入图片  if (IDOK == dlg.DoModal()) {  if (!m\_Image\_Match.IsNull())  m\_Image\_Match.Destroy();  m\_Image\_Match.Load(dlg.GetPathName());  if (m\_Image\_Match.IsNull())return;  int w = m\_Image\_Match.GetWidth();//获得图像的宽度  int h = m\_Image\_Match.GetHeight();//获得图像的高度  int arr[256] = { 0 };  int G[256] = { 0 };//存放待匹配图片的每个像素值的统计量  int bits = m\_Image\_Match.GetBPP();  if (bits == 24 || bits == 32){  for (int i = 0; i < h; i++){  for (int j = 0; j < w; j++){  int ave = 0.1140 \*m\_Image\_Match.m\_pBits[0][i][j] + 0.5870 \*m\_Image\_Match.m\_pBits[1][i][j] + 0.2989 \*m\_Image\_Match.m\_pBits[2][i][j];  m\_Image\_Match.m\_pBits[0][i][j] = ave; // change image to gray  m\_Image\_Match.m\_pBits[1][i][j] = ave;  m\_Image\_Match.m\_pBits[2][i][j] = ave;  }  }  }  for (int i = 0; i < h; i++){  for (int j = 0; j < w; j++){  BYTE value = m\_Image\_Match.m\_pBits[0][i][j];  arr[value] ++;//计算统计直方图  }  }  if (m\_Image.IsNull()) return;//判断图像是否为空，空图像操作会出现未知的错误  int w0 = w;  int h0 = h;  w = m\_Image.GetWidth();//获得图像的宽度  h = m\_Image.GetHeight();//获得图像的高度  for (int i = 0; i < 256; i++){  for (int j = 0; j <= i; j++){  G[i] += float(arr[j]) / w0 / h0 \* w \* h;  } //计算映射到图片中每个像素值的统计量  }  bits = m\_Image.GetBPP();  int hierarchical = 2;  int n[256] = { 0 };//存放源图片的每个像素值的统计量  int nMap[256] = { 0 };//存放源图到目标图片的像素值映射表  if (bits == 24 || bits == 32){  for (int i = 0; i < h; i++){  for (int j = 0; j < w; j++){  int ave = 0.1140 \*m\_Image.m\_pBits[0][i][j] + 0.5870 \*m\_Image.m\_pBits[1][i][j] + 0.2989 \*m\_Image.m\_pBits[2][i][j];  m\_Image.m\_pBits[0][i][j] = ave;  m\_Image.m\_pBits[1][i][j] = ave;  m\_Image.m\_pBits[2][i][j] = ave;  }  }  }  for (int i = 0; i < h; i++){  for (int j = 0; j < w; j++){  BYTE value = m\_Image.m\_pBits[0][i][j];  n[value] ++;//源图的统计直方图  }  }  int count\_g = 0;  int count\_n = 0;  int sum = 0;  while (true) {  if (count\_n == 256) break;  if (sum < G[count\_g]) {  //count\_n++;  sum += n[count\_n++];  continue;  }  else {  nMap[count\_n] = count\_g;  count\_g++;  }  if (count\_g == 255) {  nMap[255] = 255;  break;  }  }  int k = nMap[255];  for (int i = 255; i >= 0; i--){  if (nMap[i] == 0) nMap[i] = k;  else k = nMap[i];  }  for (int i = 0; i < h; i++){  for (int j = 0; j < w; j++)  int value = m\_Image.m\_pBits[0][i][j];  m\_Image.m\_pBits[0][i][j] = nMap[value];  m\_Image.m\_pBits[1][i][j] = nMap[value];  m\_Image.m\_pBits[2][i][j] = nMap[value];  }  }  m\_Image.calcHistogram();  paintHistDialog dlg1(this);//用一个CImage\_ProcessingView的指针取初始化dlg  dlg1.DoModal();  Invalidate(1);  }  } |

##### 实现结果展示

1. 直方图均衡

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| 均衡前原图 | 均衡前归一化直方图 |
| 均衡后图 | 均衡后归一化直方图 |

1. 直方图规范化

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| 直方图规定前原图 | 直方图规定前原直方图 |
| 规定模板原图 | 规定模板直方图 |
| 规定后图 | 规定后直方图 |

编程3：编程实现图像均值滤波、中值滤波。

##### 源代码及重点语句的注释

1、均值滤波

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| void CImage\_ProcessingView::OnMeanfilter(){  // TODO: 在此添加命令处理程序代码  if (m\_Image.IsNull()) return;//判断图像是否为空，对空图像操作会出现未知的错误  int w = m\_Image.GetWidth();//获得图像的宽度  int h = m\_Image.GetHeight();//获得图像的高度  int bits = m\_Image.GetBPP();  int hierarchical = 2;  MyImage\_ m\_Image2;  m\_Image2.Load(filename);  for (int i = 1; i < h - 1; i++){  for (int j = 1; j < w - 1; j++){//对像素点领域内的像素值进行相加求平均  m\_Image.m\_pBits[0][i][j] = m\_Image2.m\_pBits[0][i - 1][j - 1] / 9 + m\_Image2.m\_pBits[0][i][j - 1] / 9 + m\_Image2.m\_pBits[0][i + 1][j - 1] / 9 + m\_Image2.m\_pBits[0][i - 1][j] / 9 + m\_Image2.m\_pBits[0][i][j] / 9 + m\_Image2.m\_pBits[0][i + 1][j] / 9 + m\_Image2.m\_pBits[0][i - 1][j + 1] / 9 + m\_Image2.m\_pBits[0][i][j + 1] / 9 + m\_Image2.m\_pBits[0][i + 1][j + 1] / 9;  m\_Image.m\_pBits[1][i][j] = m\_Image2.m\_pBits[1][i - 1][j - 1] / 9 + m\_Image2.m\_pBits[1][i][j - 1] / 9 + m\_Image2.m\_pBits[1][i + 1][j - 1] / 9 + m\_Image2.m\_pBits[1][i - 1][j] / 9 + m\_Image2.m\_pBits[1][i][j] / 9 + m\_Image2.m\_pBits[1][i + 1][j] / 9 + m\_Image2.m\_pBits[1][i - 1][j + 1] / 9 + m\_Image2.m\_pBits[1][i][j + 1] / 9 + m\_Image2.m\_pBits[1][i + 1][j + 1] / 9;  m\_Image.m\_pBits[2][i][j] = m\_Image2.m\_pBits[2][i - 1][j - 1] / 9 + m\_Image2.m\_pBits[2][i][j - 1] / 9 + m\_Image2.m\_pBits[2][i + 1][j - 1] / 9 + m\_Image2.m\_pBits[2][i - 1][j] / 9 + m\_Image2.m\_pBits[2][i][j] / 9 + m\_Image2.m\_pBits[2][i + 1][j] / 9 + m\_Image2.m\_pBits[2][i - 1][j + 1] / 9 + m\_Image2.m\_pBits[2][i][j + 1] / 9 + m\_Image2.m\_pBits[2][i + 1][j + 1] / 9;  }  }  Invalidate(1);  } |

2、中值滤波

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| void CImage\_ProcessingView::OnMidfilter(){  // TODO: 在此添加命令处理程序代码  if (m\_Image.IsNull()) return;//判断图像是否为空，对空图像操作会出现未知的错误  int w = m\_Image.GetWidth();//获得图像的宽度  int h = m\_Image.GetHeight();//获得图像的高度  int bits = m\_Image.GetBPP();  int hierarchical = 2;  MyImage\_ m\_Image2;  m\_Image2.Load(filename);  for (int i = 1; i < h - 1; i++){  for (int j = 1; j < w - 1; j++){  for (int k = 0; k < 3; k++){  int arr[9] = {m\_Image2.m\_pBits[k][i - 1][j - 1], m\_Image2.m\_pBits[k][i][j - 1], m\_Image2.m\_pBits[k][i + 1][j - 1], m\_Image2.m\_pBits[k][i - 1][j], m\_Image2.m\_pBits[k][i][j], m\_Image2.m\_pBits[k][i + 1][j], m\_Image2.m\_pBits[k][i - 1][j + 1], m\_Image2.m\_pBits[k][i][j + 1], m\_Image2.m\_pBits[k][i + 1][j + 1]}; //将像素点领域内的像素值放到数组内  sort(arr, arr + 9); //对图像像素值进行排序  m\_Image.m\_pBits[k][i][j] = arr[4]; //取排序后的中值  }  }  }  Invalidate(1);  } |

##### 实现结果展示

1. 均值滤波

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原图 均值滤波后的图

1. 中值滤波

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原图 中值滤波后的图

### 第四章

编程1：实现一幅图像的FFT变换，显示其频谱图像，验证其平移特性、旋转特性等。

##### 流程图

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##### 源代码及重点语句的注释

1、OnTransformfft函数

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| void CImage\_ProcessingView::OnTransformfft(){  if (m\_Image.IsNull()) return;//判断图像是否为空，对空图像操作会出现未知的错误  int w = m\_Image.GetWidth();//获取高度和宽度  int h = m\_Image.GetHeight();  if (!m\_Imagesrc.IsNull()) m\_Imagesrc.Destroy();  m\_Imagesrc.Load(filename); //记住原图文件名和原图  int bits = m\_Image.GetBPP();  if (w & w - 1 != 0 || h & h - 1 != 0) return; //不满足2n条件fft则返回  if (bits == 24 || bits == 32){ //转为灰度图  for (int i = 0; i < h; i++){  for (int j = 0; j < w; j++){  int ave = 0.1140 \*m\_Image.m\_pBits[0][i][j] + 0.5870 \*m\_Image.m\_pBits[1][i][j] + 0.2989 \*m\_Image.m\_pBits[2][i][j];  m\_Image.m\_pBits[0][i][j] = ave;  m\_Image.m\_pBits[1][i][j] = ave;  m\_Image.m\_pBits[2][i][j] = ave;  }  }  }  complex\_mat<float> F(w, h); //创建一个复数矩阵存放fft结果  for (int i = 0; i < h; i++){  for (int j = 0; j < w; j++){//将图片数值转为复数型存放在F中以便调用  F.y[i][j] = complex<float>(m\_Image.m\_pBits[0][i][j], 0);  }  }  fft2<float>(F.y, w, h);//现在的F.y就是fft后的结果  fft\_shift<float>(F.y, w, h); //做fftshift将中心放在图片原点  float max = log(1 + abs(F.y[0][0]));  float min = log(1 + abs(F.y[0][0])); //保存增强图片的最大最小值以便归一化  for (int i = 0; i < h; i++){  for (int j = 0; j < w; j++){  float value = log(1 + abs(F.y[i][j]));  if (value > max) max = value;  if (value < min) min = value;  }  }  float inner = 0;  inner = (max - min) / 255;  for (int i = 0; i < h; i++){  for (int j = 0; j < w; j++){  float value = log(1 + abs(F.y[i][j])); //对图片做增强  value = float((value + min) / inner);  if (value > 255) value = 255;  if (value < 0) value = 0;  m\_Image.m\_pBits[0][i][j] = int(value); //归一化后赋值到m\_Image中  m\_Image.m\_pBits[1][i][j] = int(value);  m\_Image.m\_pBits[2][i][j] = int(value);  }  }  m\_Image.flag = 1; //显示频谱图（保存在m\_Image中）和原图（保存在m\_Imagesrc中）  Invalidate(1);  } |

2、构造的complex\_mat.hpp以便fft调用

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| #ifndef COMPLEX\_MAT\_HPP  #define COMPLEX\_MAT\_HPP  #include<complex>  template <class T>  class complex\_mat {  public:  int r; // 实部  int c; // 虚部  std::complex<T> \*\*y;  complex\_mat(int r, int c) {// 构造函数  this->r = r;  this->c = c;  init();  }  ~complex\_mat() {// 析构函数  this->free();  };  void init() {  y = new complex<T>\*[r];  for (int j = 0; j < r; j++)  y[j] = new complex<T>[c];  };  void free() {  for (int j = 0; j < r; j++)  delete[] y[j];  delete[] y;  };  };  #endif // COMPLEX\_MAT\_HPP |

3、fft.hpp以便调用，内含一维fft，一维ifft，二维fft，二维fft以及fftshift函数。

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| #ifndef FFT\_TRANSFORM\_HPP  #define FFT\_TRANSFORM\_HPP  #include "complex\_mat.hpp"  using namespace std;  #define PI 3.14159265359  template <class T>  void change(complex<T> \*y, int len) {  int i, j, k;  for (i = 1, j = len / 2; i < len - 1; i++) {  if (i < j) swap(y[i], y[j]);k = len / 2;  while (j >= k) {  j = j - k;  k = k / 2;  }  if (j < k) j += k;  }  }  template <class T>//一维fft函数  void fft(complex<T> y[], int len) {  change(y, len);  for (int h = 2; h <= len; h <<= 1) {// 迭代法求fft  complex<T> w(cos(-1 \* 2 \* PI / h), sin(-1 \* 2 \* PI / h)); // W  for (int j = 0; j < len; j += h) {  complex<T> wn(1, 0);  for (int k = j; k < j + h / 2; k++) {  complex<T> u = y[k];  complex<T> t = wn \* y[k + h / 2];  y[k] = u + t;  y[k + h / 2] = u - t;  wn = wn \* w;  }  }  }  }  template <class T>//一维ifft函数  void ifft(complex<T> y[], int len) {  for (int h = 0; h < len; h++) {  y[h] /= len; // ifft还需除以序列总长度  }  change(y, len);  for (int h = 2; h <= len; h <<= 1) {// 迭代法  complex<T> w(cos(1 \* 2 \* PI / h), sin(1 \* 2 \* PI / h)); // -W和fft反相  for (int j = 0; j < len; j += h) {  complex<T> wn(1, 0);  for (int k = j; k < j + h / 2; k++) {  complex<T> u = y[k];  complex<T> t = wn \* y[k + h / 2];  y[k] = u + t;  y[k + h / 2] = u - t;  wn = wn \* w;  }  }  }  }  template <class T>// 二维fft函数  void fft2(complex<T> \*\*y, int c, int r) {  complex<T>\* row = new complex<T>[c];  complex<T>\* col = new complex<T>[r]; // 分别对每行和每列求一维fft得到二维fft结果  for (int i = 0; i < r; i++) {  for (int n = 0; n < c; n++) {  row[n] = y[i][n];  }  fft(row, c);  for (int n = 0; n < c; n++) {  y[i][n] = row[n];  }  }  for (int i = 0; i < c; i++) {  for (int n = 0; n < r; n++) {  col[n] = y[n][i];  }  fft(col, r);  for (int n = 0; n < r; n++) {  y[n][i] = col[n];  }  }  delete[] row; // 释放指针以免占用空间  delete[] col;  }  template <class T>// 二维ifft函数  void ifft2(complex<T> \*\*y, int c, int r) {  complex<T>\* row = new complex<T>[c];  complex<T>\* col = new complex<T>[r];  for (int i = 0; i < c; i++) {  for (int n = 0; n < r; n++) {  col[n] = y[n][i];  }  ifft(col, r);  for (int n = 0; n < r; n++) {  y[n][i] = col[n];  }  }  for (int i = 0; i < r; i++) {  for (int n = 0; n < c; n++) {  row[n] = y[i][n];  }  ifft(row, c);  for (int n = 0; n < c; n++) {  y[i][n] = row[n];  }  }  delete[] row;  delete[] col;  }  template <class T>// 二维fftshift函数  void fft\_shift(complex<T> \*\*y, int w, int h) {  complex\_mat<float> F\_buf(w, h);  for (int i = 0; i < w; i++){  for (int j = 0; j < h; j++){  int m = i + w / 2;  if (m > w - 1) m = i - w / 2;  F\_buf.y[i][j] = y[m][j];  }  }  for (int i = 0; i < h; i++){  for (int j = 0; j < w; j++){  int m = i + h / 2;  if (m > h - 1) m = i - h / 2;  y[j][i] = F\_buf.y[j][m];  }  }// 对fft结果每行每列分别进行循环移位操作。移位为边长的二分之一  }  #endif // !FFT\_TRANSFORM\_HPP |

##### 实现结果展示

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| 经过fft变换后的图像以及原图 |
| 旋转九十度后的fft变换结果及旋转后的图（可见fft有旋转特性） |
| 对图片进行横向循环移位后得到的fft变换结果和图（可见fft平移不变） |

编程2：采用理想、巴特沃斯、高斯滤波器实现频率域低通、高通滤波功能。

##### 源代码及重点语句的注释

1、理想低通滤波器

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2、理想高通滤波器

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1. 巴特沃斯低通滤波器

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1. 巴特沃斯高通滤波器

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1. 高斯低通滤波器

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1. 高斯高通滤波器

##### 实现结果展示

### 第四章

编程1：实现一幅图像的FFT变换，显示其频谱图像，验证其平移特性、旋转特性等。

##### 流程图

##### 源代码及重点语句的注释

##### 实现结果展示

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经过fft变换后的图像以及原图。

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