NATIONAL TAIPEI UNIVERSITY OF TECHNOLOGY

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245765 - ADVANCED DIGITAL IMAGE PROCESSING

HW#3 Grey Level Transformation & Histogram Equalization

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Problem 1 Grey Level Transformation (C/C++) (40%)

a. Enhance the image cat_bright.raw and cat_dark.raw by Power-Law and Piecewise-Linear transformation that learned in class. Show the best parameters, the gray-level transform curve and output images. (Figure, 20%; Discussion, 10%)

Ans

The concept of **Piecewise-Linear transformation** is use pre-define Gamma function to transform, Equation (1) the pixel value.

$$s_r = c \cdot r^{\gamma} \tag{1}$$

Figure 1 shows the curves for difference Gamma value apply to Gamma function.

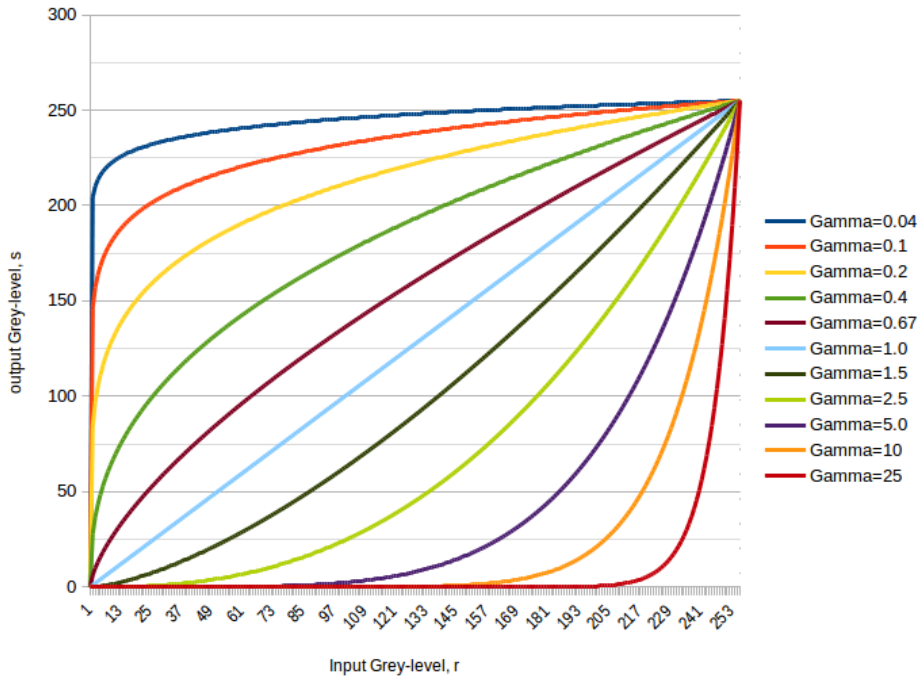


Figure 1: Power-Law Transformation in different Gamma.

The best gamma for cat_bright.raw is **10.0**. According to Figure 1, the high pixel value apply Gamma=10 curve is more sensitive.

(a) Cat bright image source. (b) Power-Law Transformation.

Figure 2: Power-Law Transformation bright image with best **Gamma 10.0**.

The best gamma for cat_dark.raw is **0.2**. For enhancing dark image the gamma value need to < 1 to make it sensitive on low pixel value.

(a) Cat dark image source. (b) Power-Law Transformation.

Figure 3: Power-Law Transformation bright image with best **Gamma 0.20**.

In **Piecewise-Linear transformation** method, we define our linear curve by self, so in Figure 4 I define a curve for scale high grey level pixel value for bright image. The enhance result of cat_bright.raw shows on Figure 5. The best values $(r_1, s_1) = (20, 10)$ and $(r_2, s_2) = (150, 50)$.

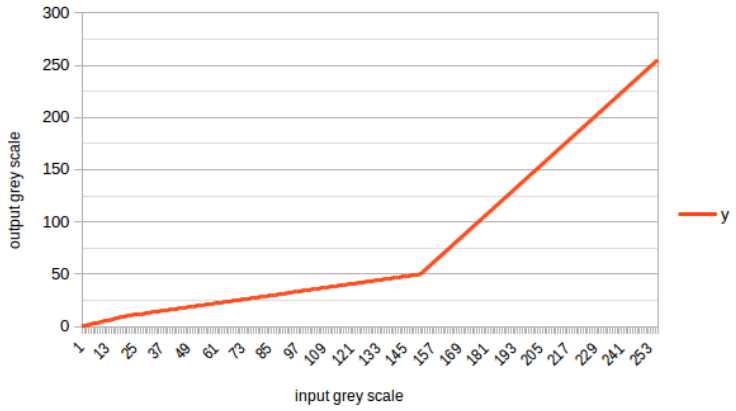


Figure 4: Power-Law Transformation in different Gamma.

(a) Cat bright image source. (b) Transformed image.

Figure 5: Piecewise-Linear transformation bright image with **Figure 4 curve**.

Figure 6, I define a linear curve for scale low gray-level value. The best values $(r_1, s_1) = (10, 150)$ and $(r_2, s_2) = (50, 200)$.

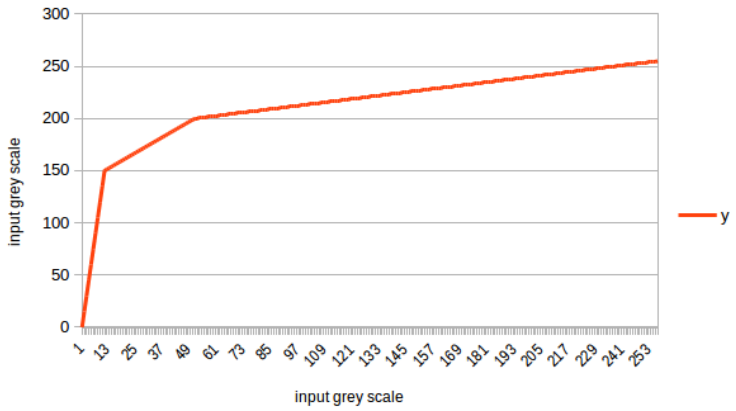


Figure 6: Power-Law Transformation in different Gamma.

(a) Cat dark image source. (b) Transformed image.

Figure 7: Piecewise-Linear transformation dark image with **Figure 6 curve**.

b. Compare and discuss the results obtained by the two methods and explain the difference.(Discussion, 10%)

Ans

The difference of Power-Low and Piecewise-Linear transformation is how we define the function. Power-Low method is very easy use but it is not good for deal with both low and high pixel value need to enhance at same time. However,

Piecewise-Linear transformation is more easy to do this but it is hard to find the best r_1 and r_2 values.

Source code for Problem 1

grey_level_transformation.hpp

```
#include <iostream>
#include <fstream>
#include <opencv2/opencv.hpp>
#include <opencv2/highgui/highgui.hpp>

const std::string SAVE_IMG_FOLDER = "../result_img/";
const double GAMMAS[] = {0.04, 0.1, 0.2, 0.4, 0.67, 1.0, 1.5, 2.5, 5.0, 10.0,
    25.0};

void loadRawFile(cv::Mat &dst_img, std::string file_path, int width, int
    height);
void showImage(std::string win_name, cv::Mat &show_img);
void saveImage(cv::Mat &img, std::string folder, std::string file_name);
double powerLaw(double L, double c, double r, double gamma);
void PowerLawTransformation(cv::Mat &src, cv::Mat &dst, double gamma);
void showAllImages(std::vector<cv::Mat> &list, std::string prefix);
void saveAllImages(std::vector<cv::Mat> &list, std::string floder, std::
    string prefix);
void plotCurves(cv::Mat &plot, std::vector<std::vector<cv::Point2f> >
    curvesPoints);
double linearFunc(uint8_t value, cv::Point2f r1s1, cv::Point2f r2s2, double L
    );
void piecewiseLinearTF(cv::Mat &src_img,
                       cv::Mat &dst_img,
                       cv::Point2f r1s1,
                       cv::Point2f r2s2);
void writeCSV( std::string folder,
               std::string file_name,
               std::vector<std::vector<cv::Point2f> > curvesPoints);
void writeCSV( std::string folder,
               std::string file_name,
               std::vector<cv::Point2f> curvesPoints);
```

grey_level_transformation.cpp

```
#include "grey_level_transformation.hpp"

void loadRawFile(cv::Mat &dst_img, std::string file_path, int width, int
    height)
{
  std::FILE* f = std::fopen(file_path.c_str(), "rb");
  // std::vector<char> buf(width*height);    // char is trivally copyable
  unsigned char buf[width][height];
  std::fread(&buf[0], sizeof buf[0], width*height, f);
```

```
  for (int i = 0; i < dst_img.rows; i++)
  {
    for (int j = 0; j < dst_img.cols; j++)
    {
      dst_img.at<char>(i, j) = buf[i][j];
    }
  }
  std::fclose(f);
}

void showImage(std::string win_name, cv::Mat &show_img)
{
  static int win_move_x = 50;
  static int win_move_y = 50;
  cv::namedWindow(win_name, 0);
  cv::resizeWindow(win_name, show_img.cols, show_img.rows);
  cv::moveWindow(win_name, win_move_x, win_move_y);
  cv::imshow(win_name, show_img); //display Image
  win_move_x +=  show_img.cols;
  if (win_move_x > 1920-256)
  {
    win_move_x = 50;
    win_move_y += (show_img.rows+35);
  }
}

void saveImage(cv::Mat &img, std::string folder, std::string file_name)
{
  std::string save_file = folder + file_name + ".png";
  cv::imwrite(save_file, img);
}

double powerLaw(double L, double c, double r, double gamma)
{
  return L * c * pow(r / L, gamma);
}

void PowerLawTransformation(cv::Mat &src, cv::Mat &dst, double gamma)
{
  double c = 1.0;
  double L = 255;
  for (int i = 0; i < src.rows; i++)
  {
    for (int j = 0; j < src.cols; j++)
    {
      double src_value = src.at<unsigned char>(i, j);
      double dst_value = powerLaw(L, c, src_value, gamma);
      dst.at<char>(i, j) = (char) dst_value;
    }
```

```
58    }
59  }
60
61  void showAllImages(std::vector<cv::Mat> &list, std::string prefix)
62  {
63    for (int i = 0; i < list.size(); i++)
64    {
65      std::string gamma = std::to_string(GAMMAS[i]);
66      gamma.erase ( gamma.find_last_not_of('0') + 2, std::string::npos );
67      showImage(prefix + " " + gamma + "gamma", list[i]);
68    }
69  }
70
71  void saveAllImages(std::vector<cv::Mat> &list, std::string floder, std::
        string prefix)
72  {
73    for (int i = 0; i < list.size(); i++)
74    {
75      std::string gamma = std::to_string(GAMMAS[i]);
76      gamma.erase ( gamma.find_last_not_of('0') + 2, std::string::npos );
77      std::string save_file = floder + prefix + gamma + ".png";
78      cv::imwrite(save_file, list[i]);
79    }
80  }
81
82  void plotCurves(cv::Mat &plot, std::vector<std::vector<cv::Point2f> >
        curvesPoints)
83  {
84    for (int i = 0; i < curvesPoints.size(); i++)
85    {
86      cv::Mat curve(curvesPoints[i], true);
87      curve.convertTo(curve, CV_32S); //adapt type for polylines
88      polylines(plot, curve, false, cv::Scalar(255), 2, CV_AA);
89    }
90  }
91
92  double linearFunc(uint8_t value, cv::Point2f r1s1, cv::Point2f r2s2, double L
        = 255)
93  {
94    if (value >= 0 && value < r1s1.x)
95    {
96      double m = r1s1.y / r1s1.x;
97      return m*value;
98    }
99    else if(value >= r1s1.x && value < r2s2.x)
100   {
101     double m = (r1s1.y - r2s2.y) / (r1s1.x - r2s2.x);
102     double c = r1s1.y - m * r1s1.x;
103     return m * value + c;
```

```
104   }
105   else if(value >= r2s2.x)
106   {
107     double m = (L - r2s2.y) / (L - r2s2.x);
108     double c = r2s2.y - m * r2s2.x;
109     return m * value + c;
110   }
111   else
112   {
113     return -1;
114   }
115 }
116
117 void piecewiseLinearTF(cv::Mat &src_img,
118                        cv::Mat &dst_img,
119                        cv::Point2f r1s1,
120                        cv::Point2f r2s2)
121 {
122   for (int i = 0; i < src_img.rows; i++)
123   {
124     for (int j = 0; j < src_img.cols; j++)
125     {
126       dst_img.at<char>(i, j) = linearFunc(src_img.at<char>(i, j), r1s1, r2s2)
      ;
127     }
128   }
129 }
130
131 void writeCSV( std::string folder,
132                std::string file_name,
133                std::vector<std::vector<cv::Point2f> > curvesPoints)
134 {
135   std::ofstream myfile(folder+file_name+".csv");
136   myfile << "x";
137   for (int i = 0; i < curvesPoints.size(); i++)
138   {
139     myfile << ",y" + std::to_string(i);
140   }
141   myfile << std::endl;
142   for (int i = 0; i < curvesPoints[0].size(); i++)
143   {
144     myfile << curvesPoints[0][i].x << ",";
145     for (int j = 0; j < curvesPoints.size(); j++)
146     {
147       myfile << curvesPoints[j][i].y;
148       if (curvesPoints.size()-1 != j)
149       {
150         myfile << ",";
151       }
```

```
    }
    myfile << std::endl;
  }
  myfile.close();
}
void writeCSV( std::string folder,
               std::string file_name,
               std::vector<cv::Point2f> curvesPoints)
{
  std::ofstream myfile(folder+file_name+".csv");
  myfile << "x,y" << std::endl;
  for (int i = 0; i < curvesPoints.size(); i++)
  {
    myfile << curvesPoints[i].x << "," << curvesPoints[i].y << std::endl;
  }
  myfile.close();
}

int main(int argc, char **argv)
{
  cv::Mat cat_b_src(256, 256, CV_8UC1);
  cv::Mat cat_d_src(256, 256, CV_8UC1);
  loadRawFile(cat_b_src, "../images/cat_bright.raw", 256, 256);
  loadRawFile(cat_d_src, "../images/cat_dark.raw", 256, 256);

  // Power-Law Transformation
  std::vector<cv::Mat> cat_b_img_lst;
  std::vector<cv::Mat> cat_d_img_lst;
  std::vector<std::vector<cv::Point2f> > curvesPoints;
  for (int i = 0; i < sizeof(GAMMAS)/sizeof(double); i++)
  {
    cv::Mat cat_b_transtormed(256, 256, CV_8UC1);
    cv::Mat cat_d_transtormed(256, 256, CV_8UC1);
    PowerLawTransformation(cat_b_src, cat_b_transtormed, GAMMAS[i]);
    PowerLawTransformation(cat_d_src, cat_d_transtormed, GAMMAS[i]);
    cat_b_img_lst.push_back(cat_b_transtormed);
    cat_d_img_lst.push_back(cat_d_transtormed);
    // insert data to curve
    std::vector<cv::Point2f> curvePoints;
    for (int j = 0; j < 256; j++)
    {
      cv::Point2f point(j, powerLaw(255, 1.0, j, GAMMAS[i]));
      curvePoints.push_back(point);
    }
    curvesPoints.push_back(curvePoints);
  }
  cv::Mat plot_img(256, 256, CV_8UC1, cv::Scalar(0));
  plotCurves(plot_img, curvesPoints);

```

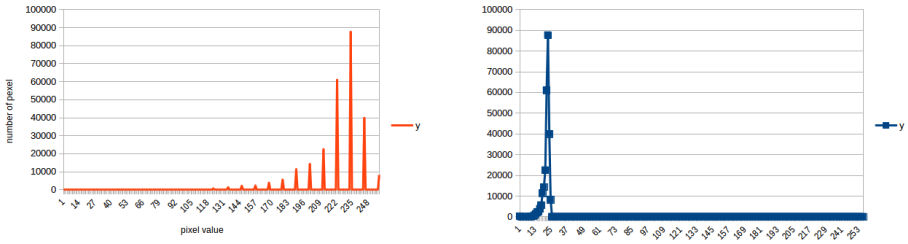
```
201   // Piecewise-Linear Transformation
202   cv::Mat cat_b_plt(256, 256, CV_8UC1);
203   cv::Mat cat_d_plt(256, 256, CV_8UC1);
204   piecewiseLinearTF(cat_b_src, cat_b_plt, cv::Point2f(20,10), cv::Point2f
        (150,50));
205   piecewiseLinearTF(cat_d_src, cat_d_plt, cv::Point2f(10,150), cv::Point2f
        (50,200));
206   std::vector<cv::Point2f> piecewise_curve_bright;
207   std::vector<cv::Point2f> piecewise_curve_dark;
208   for (int i = 0; i < 256; i++)
209   {
210     piecewise_curve_bright.push_back(cv::Point2f(i, linearFunc(i, cv::Point2f
        (20, 10), cv::Point2f(150,50))));
211     piecewise_curve_dark.push_back(cv::Point2f(i, linearFunc(i, cv::Point2f
        (10, 150), cv::Point2f(50,200))));
212   }
213
214   // showImage("Power Law", plot_img);
215   // showAllImages(cat_b_img_lst, "cat b");
216   // showAllImages(cat_d_img_lst, "cat d");
217   // showImage("src cat bright", cat_b_src);
218   // showImage("PLT cat bright", cat_b_plt);
219   // showImage("src cat dark", cat_d_src);
220   // showImage("PLT cat dark", cat_d_plt);
221   writeCSV("../result_plot_data/", "Power-Law", curvesPoints);
222   writeCSV("../result_plot_data/", "piecewise_curve_bright",
        piecewise_curve_bright);
223   writeCSV("../result_plot_data/", "piecewise_curve_dark",
        piecewise_curve_dark);
224   saveAllImages(cat_b_img_lst, "../result_img/problem1/power_law/", "
        cat_bright");
225   saveAllImages(cat_d_img_lst, "../result_img/problem1/power_law/", "cat_dark
        ");
226   saveImage(cat_b_src, "../result_img/problem1/", "cat_bright_src");
227   saveImage(cat_b_plt, "../result_img/problem1/", "cat_bright_plt");
228   saveImage(cat_d_src, "../result_img/problem1/", "cat_dark_src");
229   saveImage(cat_d_plt, "../result_img/problem1/", "cat_dark_plt");
230   cv::waitKey(0);
231   return 0;
232 }
```

Problem 2 Histogram Equalization (C/C++) (60%)

a. Plot the histogram of livingroom_bright.raw and livingroom_dark.raw. Discuss the difference among these histograms. (Figure, 10%; Discussion, 10%)

Ans

The difference between bright and dark image histogram are distributed on different mean and variance. For example, the histogram of bright image, The most pixel are locate in high value area (see Figure 8a). On the other, dark image pixel value are concentrate on low value part (see Figure 8b).



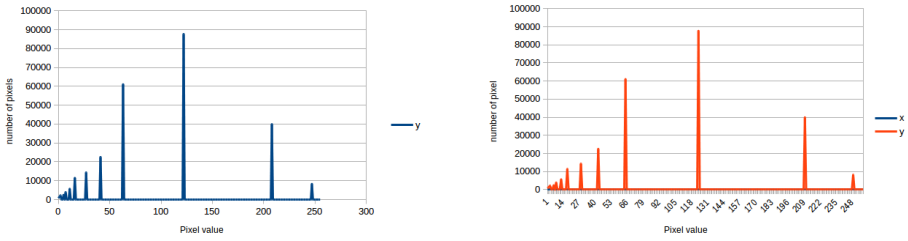
(a) Living room bright. (b) Living room dark.

Figure 8: Histofram of living room images

b. Perform histogram equalization on livingroom_bright.raw and livingroom_dark.raw. Plot their histograms after equalization and compare the results, will the result be the same and why? (Figure, 10%; Discussion, 10%)

Ans

The result of bright and dark living room images show on Figure 9. We can see after histogram equalization, both of dark and bright are get the same histogram distribution.



(a) Living room bright. (b) Living room dark.

Figure 9: Histofram of living room image

c. If you perform histogram equalization on cat_bright.raw and cat_dark.raw, will the result look good? Show the output images and explain what causes this situation and how to improve it. (Figure, 10%, Discussion, 10%)

Ans

In Figure 10 and Figure 11 are the images which is performed histogram equalization. The result images looks very similar. In the result images, we can see there are some false contouring effect. For solving this problem, we can thought low-pass to make images more smooth.

(a) Original bright image. (b) Equalize image.

Figure 10: Living room bright histogram equalization

(a) Original dark image. (b) Equalize image.

Figure 11: Living room dark histogram equalization

Source code for Problem 2

histogram_equalization.hpp

```
#include <iostream>
#include <fstream>
#include <opencv2/opencv.hpp>
#include <opencv2/highgui/highgui.hpp>

class HistogramEq
{
  public:
  std::vector<int> histogram;
  std::vector<int> cdf;
  std::vector<int> v_map;
  int cdf_min;
  int L;
  int pixel_num;
  HistogramEq(cv::Mat &src_img, int L);
  std::vector<int> getHistogram(cv::Mat &src_img, int L);
  std::vector<int> getCDF();
  int getHv(int v);
  std::vector<int> getEqHistofram();
  void ComputeVmap(std::vector<int> &v_map);
  cv::Mat getEqImage(cv::Mat &img_src);
};
```

histogram_equalization.cpp

```
#include "histogram_equalization.hpp"

void loadRawFile(cv::Mat &dst_img, std::string file_path, int width, int
    height)
{
  std::FILE* f = std::fopen(file_path.c_str(), "rb");
  // std::vector<char> buf(width*height);    // char is trivally copyable
  unsigned char buf[width][height];
  std::fread(&buf[0], sizeof buf[0], width*height, f);
  for (int i = 0; i < dst_img.rows; i++)
  {
    for (int j = 0; j < dst_img.cols; j++)
    {
      dst_img.at<char>(i, j) = buf[i][j];
    }
  }
  std::fclose(f);
}

void showImage(std::string win_name, cv::Mat &show_img)
{
  static int win_move_x = 50;
```

```
22    static int win_move_y = 50;
23    cv::namedWindow(win_name, 0);
24    cv::resizeWindow(win_name, show_img.cols, show_img.rows);
25    cv::moveWindow(win_name, win_move_x, win_move_y);
26    cv::imshow(win_name, show_img); //display Image
27    win_move_x +=  show_img.cols;
28    if (win_move_x > 1920-256)
29    {
30      win_move_x = 50;
31      win_move_y += (show_img.rows+35);
32    }
33  }
34
35  void writeCSV( std::string folder,
36                 std::string file_name,
37                 std::vector<int> curvesPoints)
38  {
39    std::ofstream myfile(folder+file_name+".csv");
40    myfile << "x,y" << std::endl;
41    for (int i = 0; i < curvesPoints.size(); i++)
42    {
43      myfile << i << "," << curvesPoints[i] << std::endl;
44    }
45    myfile.close();
46  }
47
48  void saveImage(cv::Mat &img, std::string folder, std::string file_name)
49  {
50    std::string save_file = folder + file_name + ".png";
51    cv::imwrite(save_file, img);
52  }
53
54  HistogramEq::HistogramEq(cv::Mat &src_img, int L=256)
55  {
56    this->histogram = this->getHistogram(src_img, L);
57    this->cdf = this->getCDF();
58    this->L = L;
59    this->pixel_num = src_img.cols * src_img.rows;
60    this->ComputeVmap(this->v_map);
61  }
62
63  std::vector<int> HistogramEq::getHistogram(cv::Mat &src_img, int L=256)
64  {
65    std::vector<int> his(L, 0.0);
66    for (int i = 0; i < src_img.rows; i++)
67    {
68      for (int j = 0; j < src_img.cols; j++)
69      {
70        his[src_img.at<uint8_t>(i, j)] += 1.0;
```

```
71      }
72    }
73    return his;
74  }
75
76  std::vector<int> HistogramEq::getCDF()
77  {
78    std::vector<int> his_src = this->histogram;
79    std::vector<int> cdf(his_src.size());
80    int cdf_count = his_src[0];
81    int cdf_min = 0;
82    for (int i = 0; i < his_src.size(); i++)
83    {
84      cdf[i] = cdf_count;
85      if (cdf_min == 0 && cdf_count != 0) cdf_min = cdf_count;
86      cdf_count += his_src[i];
87    }
88    this->cdf_min = cdf_min;
89    return cdf;
90  }
91
92  int HistogramEq::getHv(int v)
93  {
94    return ((double)(this->cdf[v] - this->cdf_min) / (double)(this->pixel_num))
         * (this->L - 1);
95  }
96
97  std::vector<int> HistogramEq::getEqHistofram()
98  {
99    std::vector<int> eq_his(this->histogram.size());
100   for (int i = 0; i < eq_his.size(); i++)
101   {
102     eq_his[this->getHv(i)] = this->histogram[i];
103   }
104   return eq_his;
105 }
106
107 void HistogramEq::ComputeVmap(std::vector<int> &v_map)
108 {
109   v_map.resize(this->histogram.size());
110   for (int i = 0; i < this->histogram.size(); i++)
111   {
112     v_map[i] = this->getHv(i);
113   }
114 }
115
116 cv::Mat HistogramEq::getEqImage(cv::Mat &img_src)
117 {
118   cv::Mat eq_img(img_src.rows, img_src.cols, CV_8UC1);
```

```
119   for (int i = 0; i < img_src.rows; i++)
120   {
121     for (int j = 0; j < img_src.cols; j++)
122     {
123       eq_img.at<char>(i, j) = this->v_map[img_src.at<uint8_t>(i, j)];
124     }
125   }
126   return eq_img;
127 }
128
129 int main(int argc, char **argv)
130 {
131   cv::Mat lvroom_b_src(512, 512, CV_8UC1);
132   cv::Mat lvroom_d_src(512, 512, CV_8UC1);
133   loadRawFile(lvroom_b_src, "../images/livingroom_bright.raw", 512, 512);
134   loadRawFile(lvroom_d_src, "../images/livingroom_dark.raw", 512, 512);
135   HistogramEq hiseq_living_b = HistogramEq(lvroom_b_src);
136   HistogramEq hiseq_living_d = HistogramEq(lvroom_d_src);
137   writeCSV("../result_plot_data/", "livingRoomBrightHis", hiseq_living_b.
        histogram);
138   writeCSV("../result_plot_data/", "livingRoomDarkHis", hiseq_living_d.
        histogram);
139   writeCSV("../result_plot_data/", "livingRoomBrightEqHis", hiseq_living_b.
        getEqHistofram());
140   writeCSV("../result_plot_data/", "livingRoomDarkEqHis", hiseq_living_d.
        getEqHistofram());
141   cv::Mat lvroom_b_eq_img = hiseq_living_b.getEqImage(lvroom_b_src);
142   cv::Mat lvroom_d_eq_img = hiseq_living_d.getEqImage(lvroom_d_src);
143   saveImage(lvroom_b_src, "../result_img/problem2/", "livingroom_bright_src")
        ;
144   saveImage(lvroom_b_eq_img, "../result_img/problem2/", "
        livingroom_eq_bright_src");
145   saveImage(lvroom_d_src, "../result_img/problem2/", "livingroom_dark_src");
146   saveImage(lvroom_d_eq_img, "../result_img/problem2/", "
        livingroom_eq_dark_src");
147   showImage("livingroom bright", lvroom_b_src);
148   showImage("livingroom eq bright", lvroom_b_eq_img);
149   showImage("livingroom dark", lvroom_d_src);
150   showImage("livingroom eq dark", lvroom_d_eq_img);
151   cv::waitKey(0);
152   return 0;
153 }
```