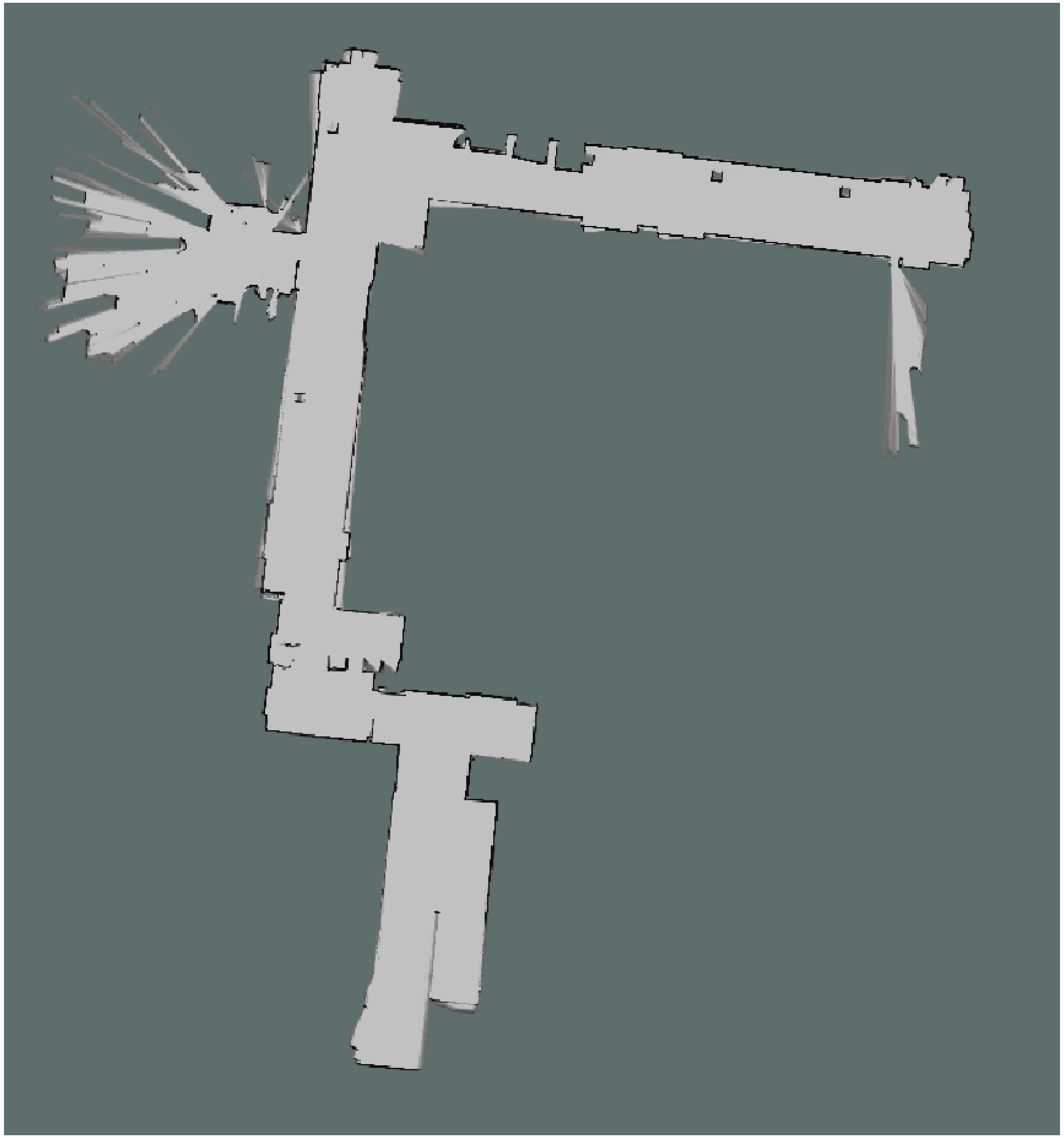
1. 补充代码，通过覆盖栅格建图算法进行栅格地图构建；（3 分）

```
//start of TODO 对对应的map的cell信息进行更新. （1,2,3题内容）
//1
GridIndex beamPointIndex = ConvertWorld2GridIndex(world_x, world_y);
std::vector<GridIndex> beamTraceindexes = TraceLine(robotIndex.x, robotIndex.y, beamPointIndex.x, beamPointIndex.y);
for(auto index : beamTraceindexes)
{
    if(isValidGridIndex(index))
    {
        int tmpLinearIndex = GridIndexToLinearIndex(index);
        if(pMap[tmpLinearIndex] == 0) continue;
        pMap[tmpLinearIndex] += mapParams.log_free;
    }else{
        std::cerr << "index is invalid!!!" << std::endl;
    }
}
if(isValidGridIndex(beamPointIndex))
{
    int tmpLinearIndex = GridIndexToLinearIndex(beamPointIndex);

    pMap[tmpLinearIndex] += mapParams.log_occ;
    if(pMap[tmpLinearIndex] >= 100) pMap[tmpLinearIndex] = 100;
}else{
    std::cerr << "beamPointIndex is invalid!!!" << std::endl;
}
//end of TODO
```

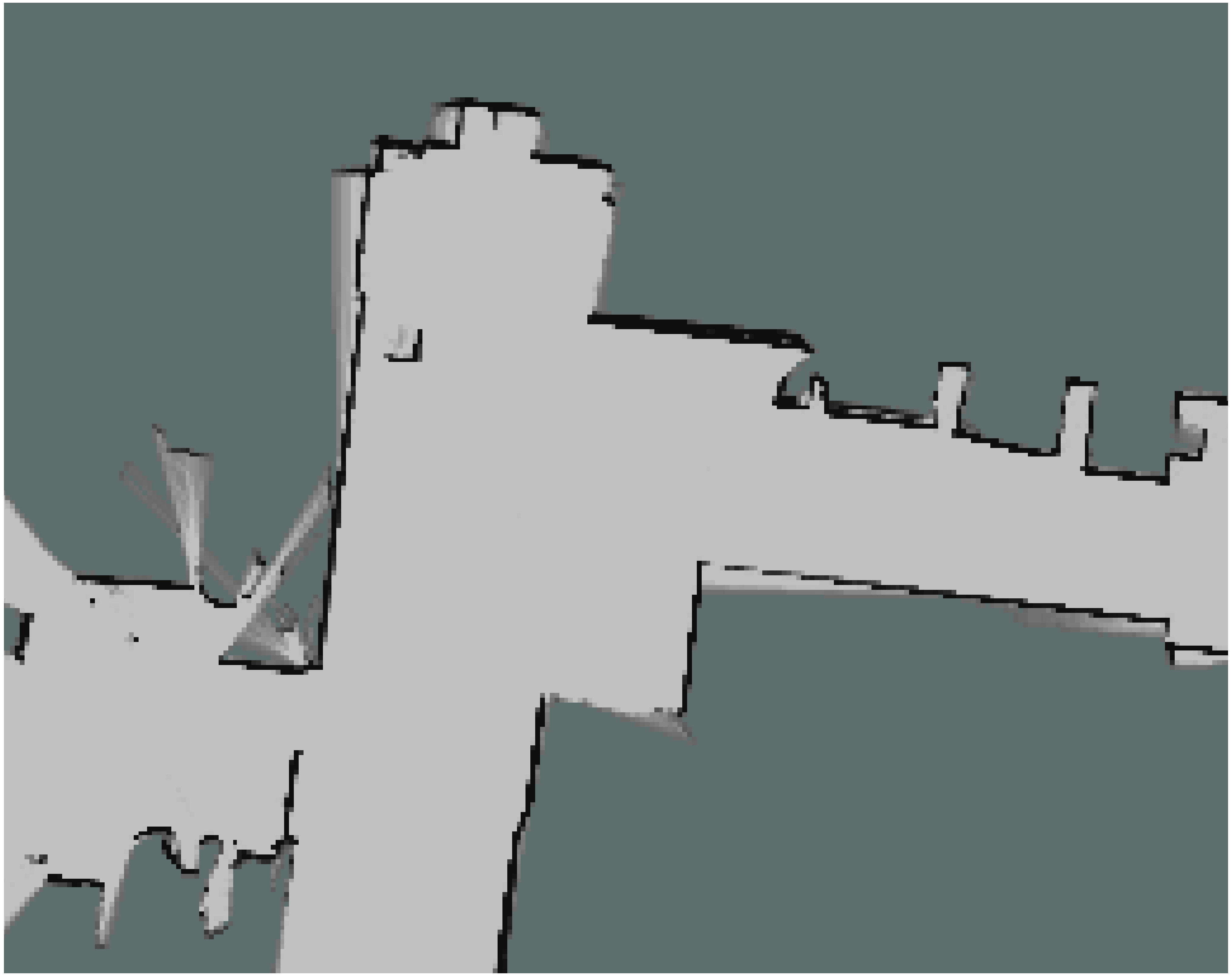
运行结果如下：

```
$ rosrun occupany_mapping occupany_mapping
poses.size(): 3701
Read Pose Good!!!
Read Angle good:1081
XX:1081
laserscans.size():3701
Read Laser Scans Good!!!!
开始建图，请稍后...
建图完毕
```

整体结果图：



局部结果图：

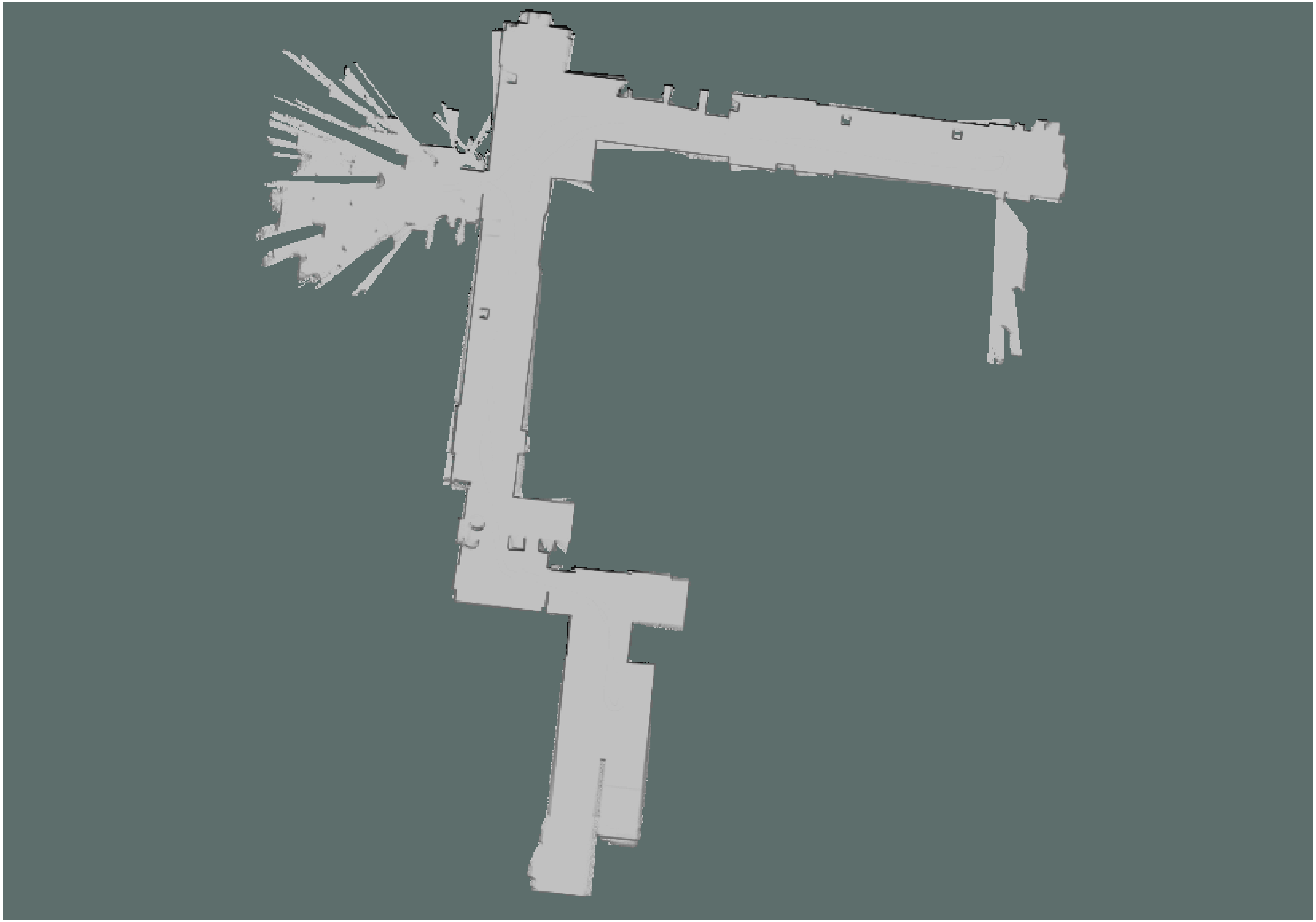


2. 将第 1 题代码改为通过计数建图算法进行栅格地图构建；（3 分）

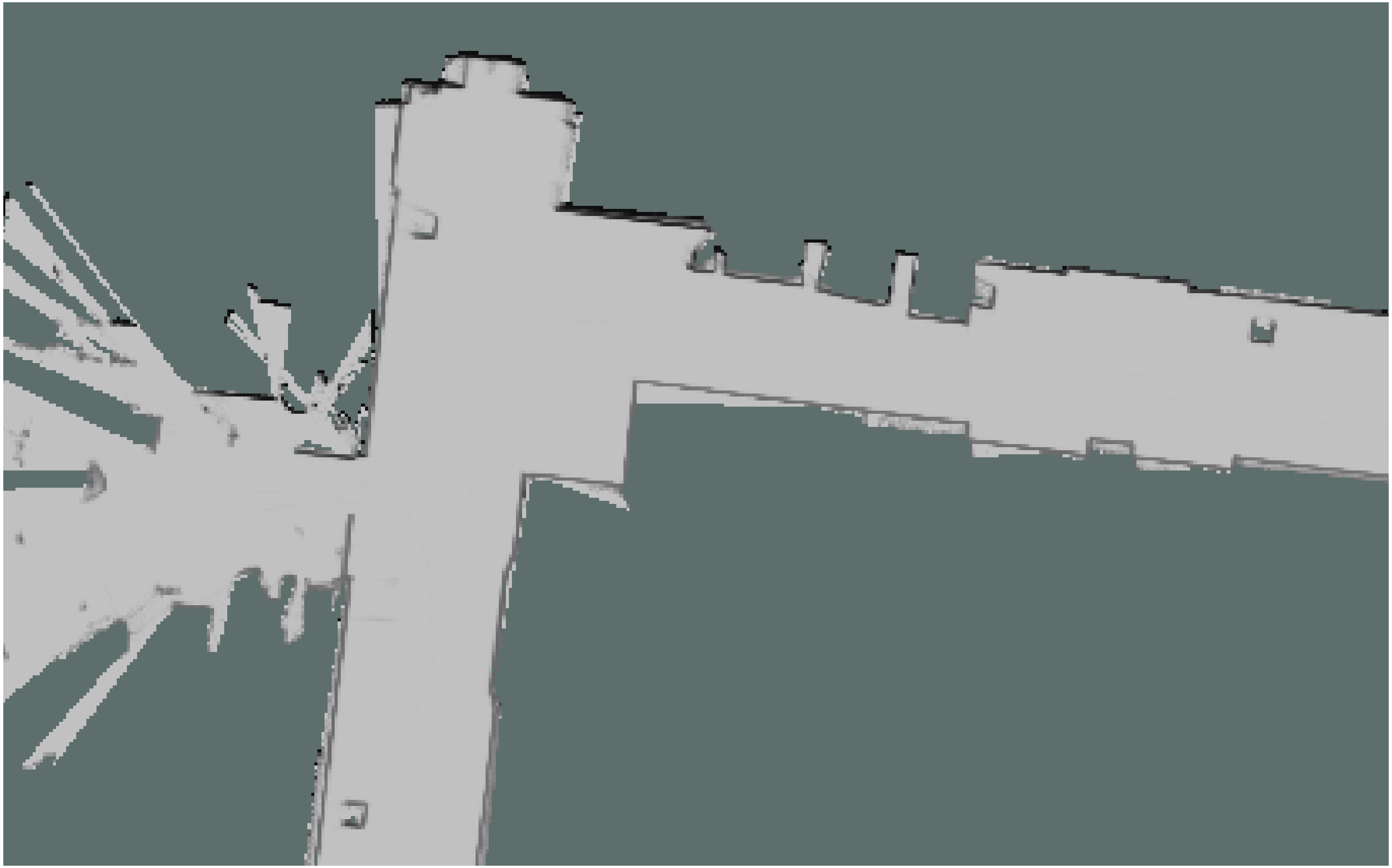
```
//start of TODO 对对应的map的cell信息进行更新. （1,2,3题内容）
//2
GridIndex beamPointIndex = ConvertWorld2GridIndex(world_x, world_y);
std::vector<GridIndex> beamTraceindexes = TraceLine(robotIndex.x, robotIndex.y, beamPointIndex.x, beamPointIndex.y);
for(auto index : beamTraceindexes)
{
    if(isValidGridIndex(index))
    {
        int tmpLinearIndex = GridIndexToLinearIndex(index);
        ++pMapMisses[tmpLinearIndex];
    }else{
        std::cerr << "index is invalid!!!" << std::endl;
    }
}
if(isValidGridIndex(beamPointIndex))
{
    int tmpLinearIndex = GridIndexToLinearIndex(beamPointIndex);
    ++pMapHits[tmpLinearIndex];
}else{
    std::cerr << "beamPointIndex is invalid!!!" << std::endl;
}
//end of TODO
```

```
//start of TODO 通过计数建图算法或TSDF算法对栅格进行更新（2,3题内容）
//2
for (int i = 0; i < mapParams.width * mapParams.height; ++i)
{
    if((pMapHits[i] + pMapMisses[i]) != 0 )
    {
        pMap[i] = (double)pMapHits[i]/(pMapHits[i] + pMapMisses[i]) * 100;
        if(pMap[i] >=35) pMap[i] = 100;
        // if(pMapHits[i] != 0)
        //     std::cout << pMapHits[i] << " " << pMapMisses[i] << " " << (int)pMap[i] << std::endl;
    }
}
//end of TODO
```

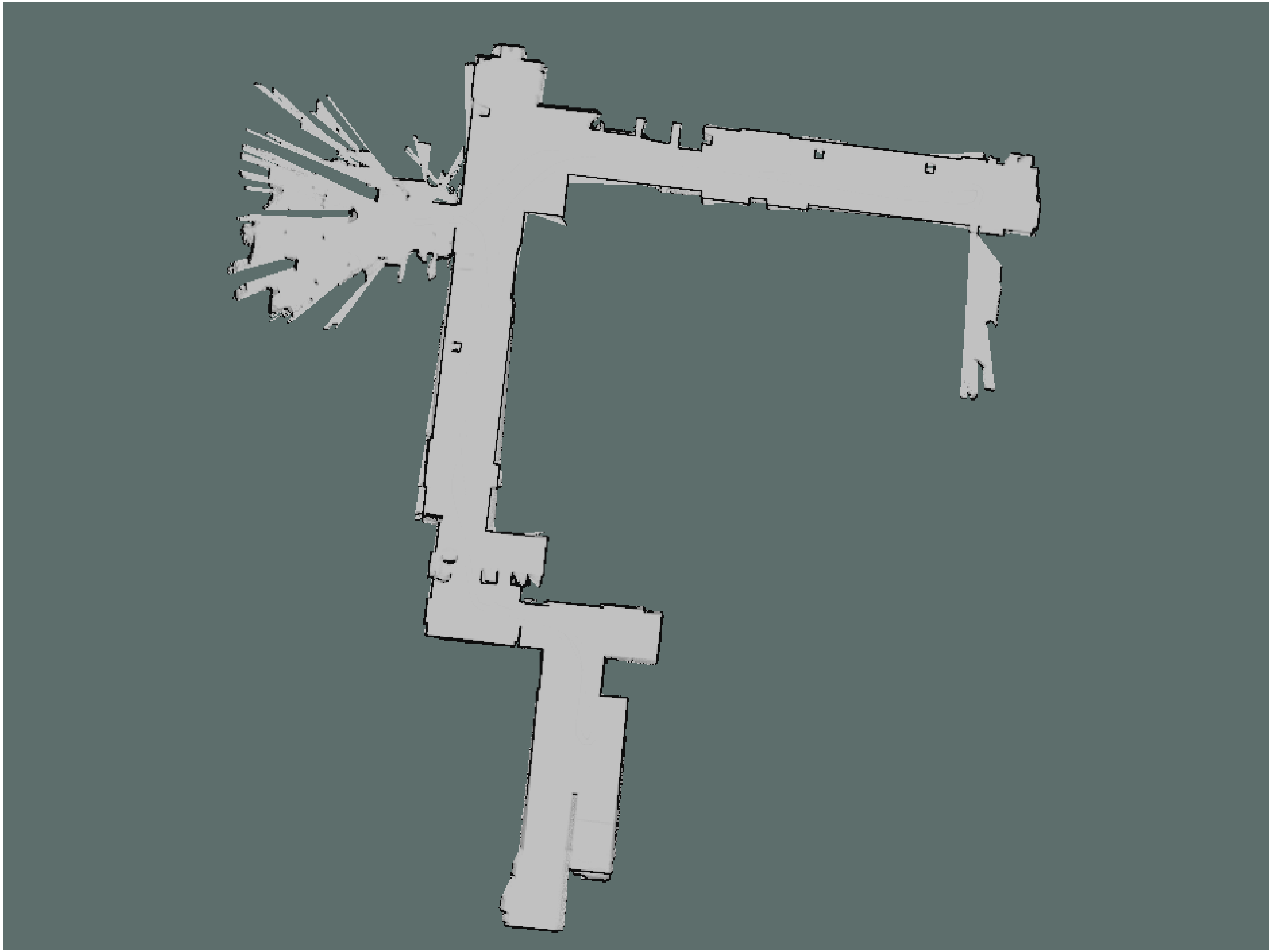
运行后发现，如果阈值设置较大，地图边界不清晰，总体结果图如下：



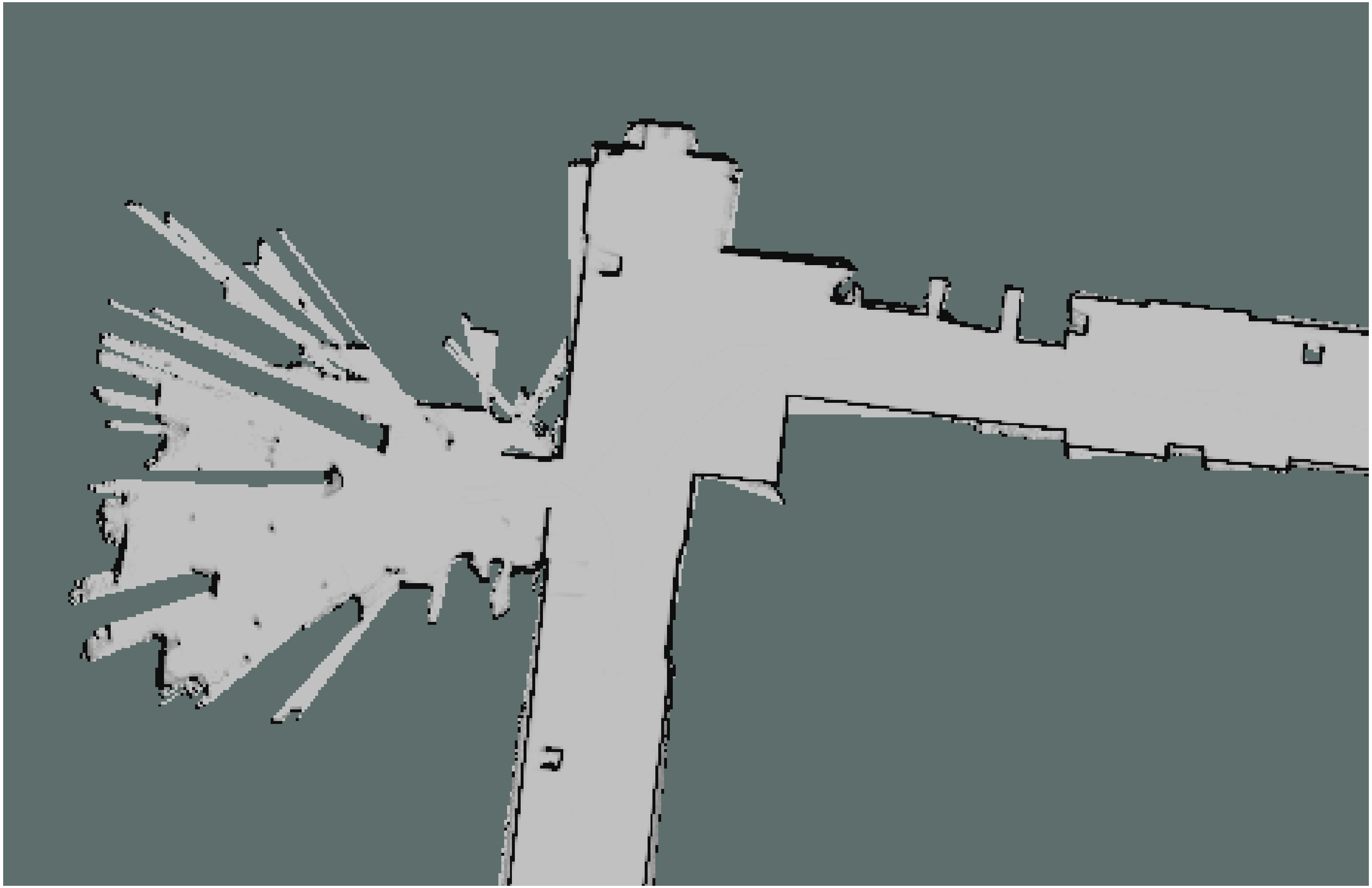
局部结果图：



将阈值改为35后，地图边界变得清晰，总体结果图如下：



局部结果图：

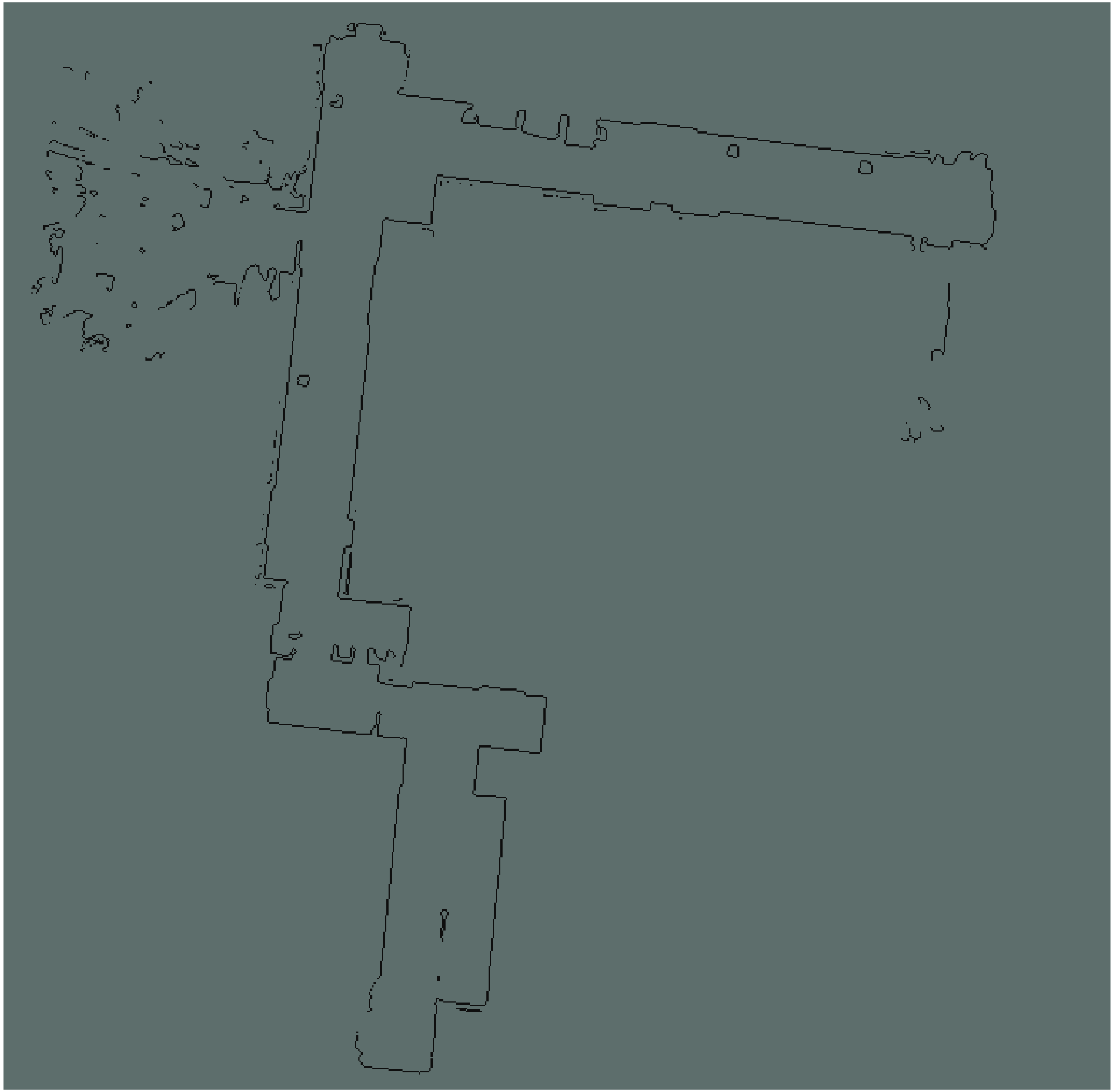


3. 将第 1 题代码改为通过 TSDF 建图算法进行栅格地图构建；（4 分）

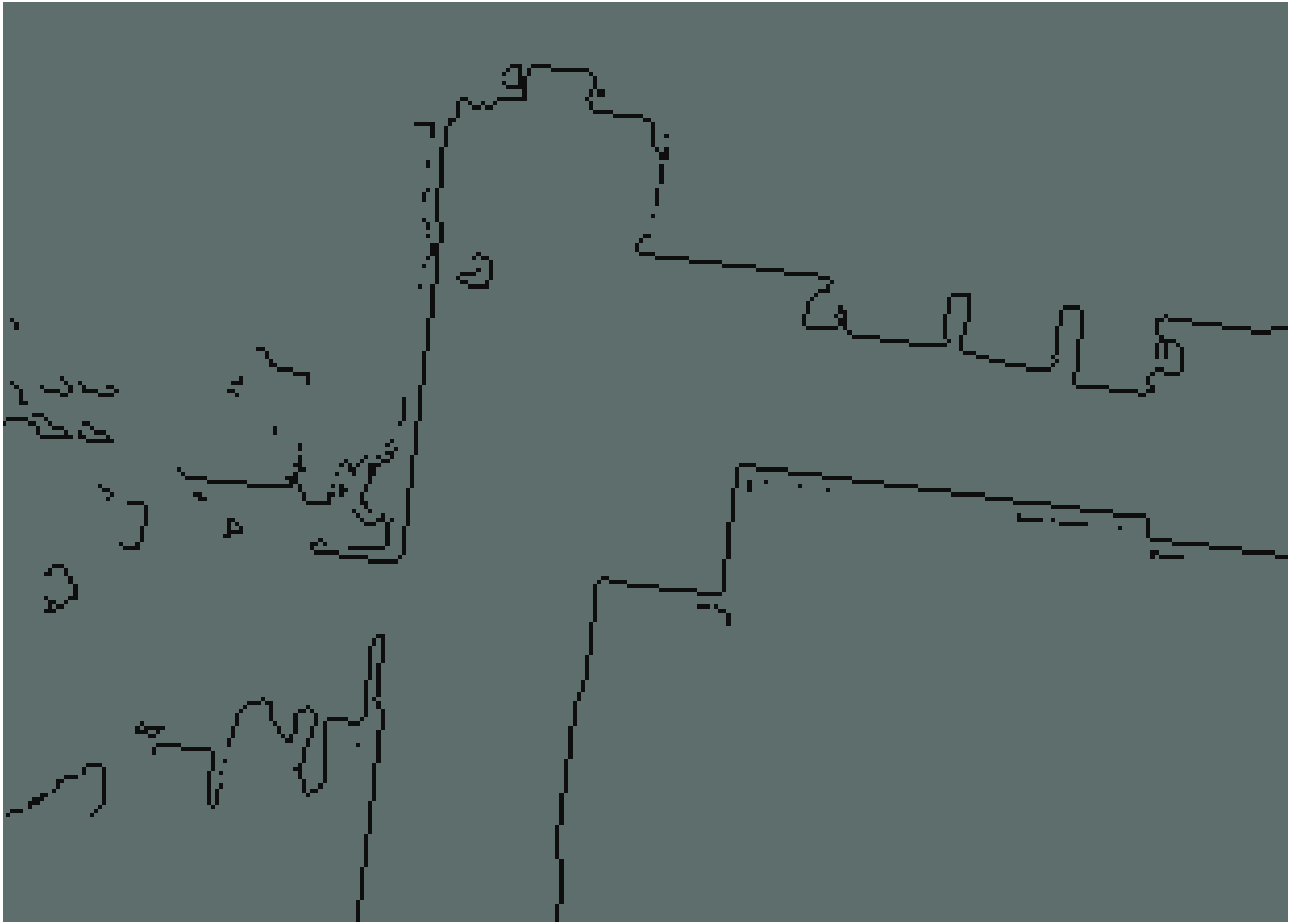
```cpp
//start of TODO 对对应的map的cell信息进行更新. （1,2,3题内容）
//3
double far_dist = dist + 0.142; //0.05*2*sqrt(2)
//计算得到该激光点的世界坐标系的坐标
double far_laser_x = far_dist * cos(angle);
double far_laser_y = far_dist * sin(angle);

double far_world_x = cos(theta) * far_laser_x - sin(theta) * far_laser_y + robotPose(0);
double far_world_y = sin(theta) * far_laser_x + cos(theta) * far_laser_y + robotPose(1);
GridIndex farBeamPointIndex = ConvertWorld2GridIndex(far_world_x, far_world_y);
std::vector<GridIndex> farBeamTraceindexes = TraceLine(robotIndex.x, robotIndex.y, farBeamPointIndex.x, farBeamPointIndex.y);
for(auto index : farBeamTraceindexes)
{
    if(isValidGridIndex(index))
    {
        //栅格坐标系转换到世界坐标系
        double x = (index.x - mapParams.offset_x) * mapParams.resolution + mapParams.origin_x;
        double y = (index.y - mapParams.offset_y) * mapParams.resolution + mapParams.origin_y;
        double d = std::sqrt((x-robotPose(0))*(x-robotPose(0)) + (y-robotPose(1))*(y-robotPose(1)));
        double sdf = dist - d;
        double tsdf = std::max(-1.0, std::min(1.0, sdf/0.1));
        int tmpLinearIndex = GridIndexToLinearIndex(index);
        pMapTSDF[tmpLinearIndex] = (pMapW[tmpLinearIndex]*pMapTSDF[tmpLinearIndex] + tsdf) / (pMapW[tmpLinearIndex] + 1);
        pMapW[tmpLinearIndex] = pMapW[tmpLinearIndex] + 1;
    }else{
        std::cerr << "index is invalid!!!" << std::endl;
    }
}
//end of TODO
```

```
//start of TODO 通过计数建图算法或TSDF算法对栅格进行更新（2,3题内容）
//3
//test code
// for (int i = 0; i < mapParams.width * mapParams.height; ++i)
// {
//     pMap[i] = pMapTSDF[i] * 100;
// }

for (int i = 0; i < mapParams.width-1; ++i) //x
{
    for(int j = 0; j < mapParams.height-1; ++j) //y
    {
        GridIndex tmpOrgIndex;
        tmpOrgIndex.SetIndex(i, j);
        int tmpOrgLinearIndex = GridIndexToLinearIndex(tmpOrgIndex);
        double tmpOrgTSDF = pMapTSDF[tmpOrgLinearIndex];
        if(tmpOrgTSDF==1 || tmpOrgTSDF==-1) continue;   //去除未击中点

        GridIndex tmpUpIndex;
        tmpUpIndex.SetIndex(i, j+1);
        int tmpUpLinearIndex = GridIndexToLinearIndex(tmpUpIndex);
        double tmpUpTSDF = pMapTSDF[tmpUpLinearIndex];

        GridIndex tmpRightIndex;
        tmpRightIndex.SetIndex(i+1, j);
        int tmpRightLinearIndex = GridIndexToLinearIndex(tmpRightIndex);
        double tmpRightTSDF = pMapTSDF[tmpRightLinearIndex];

        //没有求出精确位置，直接求出地图坐标
        if((tmpOrgTSDF<0 && tmpUpTSDF>0) || (tmpOrgTSDF>0 && tmpUpTSDF<0))
        {
            if(std::fabs(tmpOrgTSDF) < std::fabs(tmpUpTSDF))
            {
                pMap[tmpOrgLinearIndex] = 100;
            }else{
                pMap[tmpUpLinearIndex] = 100;
            }
        }
        if((tmpOrgTSDF<0 && tmpRightTSDF>0) || (tmpOrgTSDF>0 && tmpRightTSDF<0))
        {
            if(std::fabs(tmpOrgTSDF) < std::fabs(tmpRightTSDF))
            {
                pMap[tmpOrgLinearIndex] = 100;
            }else{
                pMap[tmpRightLinearIndex] = 100;
            }
        }
    }
}
//end of TODO
```

运行后总体结果图如下：



局部结果图：



4. 简答题，开放性答案：总结比较课堂所学的 3 种建图算法的优劣。（2 分）

覆盖栅格建图算法对栅格更新只需进行加法操作，更新速度较快；计数建图算法也是进行加法操作，但是需要额外存储misses和hits，需要额外占用一些内存。

上述两个算法都没有考虑传感器的不确定性，如果噪声叠加，可能出现对同一障碍物有多个栅格厚度的地图。

TSDF建图算法充分考虑传感器测量的不确定性，如果传感器的噪声服从高斯分布，那么通过TSDF进行融合，等价于通过最小二乘来进行融合，能插值出确切的曲面，构建的地图最多只有一个栅格的厚度，但是计算更复杂，更新速度较慢。