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Segmentation of digital urban maps into regions

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Abstract
With the rapid development of urban areas, the areas which may be used for new buildings are becoming smaller and smaller. Cities are divided into different areas based on the activities in these areas, a process called functional zoning. Depending on the functional zone, different kinds of buildings may be built. This thesis consists of two parts. The first part discusses segmentation of functional zones and image pre-processing such as morphological closing. The other part is about finding suitable building areas in Google maps. The thesis also presents an algorithm, implemented in Matlab, which provides a simple and efficient way of finding suitable building areas using Google maps.
Keyword: functional zoning, image processing, MATLAB, digital Google maps
1 Introduction

With the development of the world economy, the urban development has grown rapidly and occupies a very important position. There are some reasons to segment cities into different functional zones, such as historical factors, economical factors, social factors and administrative factors. However, because of functional zoning, urban problems may arise, including the Urban Heat Island Effect as well as environmental pollution. The method of urban planning becomes more and more important and useful. For my research, I intend to segment different functional zones in digital urban maps, which can then be used to decide which parts are best suitable for different purposes, such as industrial or for vegetation. This method may also have the added benefit of solving other urban problems, such as planning for outdoor activities.

As cities are divided into different functional zones, there are many different methods of doing so. For example, as can be seen in Figure 1, this city has been segmented into the zones Holy Spirits of Nature, Ritual Activities, Secular Activities, Settlements and Productivity.

![Figure 1. The functional zones of Shilin Village, Yuyao Source [18].](image)

There are other reasons why this division into zones may be a good idea – some examples are given here:

1. Historical. The historical background of the city may have a significant impact on urban function zoning [15].
2. Economic. The urban land is limited so that different sections of cities have different rent. In a market economy, it is possible to get the appropriate location when it only pays the highest rent for the economic activity [15].
3. Social. Urban populations are composed of different occupations, different cultures and different social classes. This may have an impact on the way residential areas are formed.

4. Administrative. Governments take administrative measures to develop policies and urban planning, which will also influence the segmentation of the functional zones.

There are some prominent and serious urban problems. One of them is the Urban Heat Island Effect (UHI Effect). This Effect is a phenomenon in which the city temperature is higher than the natural environment temperature in the surrounding suburban, and is caused by human activity [9]. Figure 2 shows how the temperature is affected by the environment. We can see that the areas where the vegetation has been removed are typically hotter than other areas.

![Temperature graph](image)

**Figure 2. The different temperature between day and night of an urban heat island. [12]**

As a result, small temperature changes in suburban areas will lead to larger temperature changes in urban areas. In addition, large, tall buildings obstruct the wind, thus reducing the overall urban wind speed. Another serious problem is the increasing pollution in cities.

The method of urban planning plays a crucial role in solving these problems. Urban planning focuses on the city's future development, by distributing and arranging future construction of buildings in a rational way [11]. Through urban planning, urban land can thus be used reasonably. In Google Maps, each functional zone is represented by a different color. The Google map will be changed depending on the actual situation in the development of the city. For my Google maps it shows the parts of functional zoning. The color can’t change for the processing. However, if the functional zones change, the colors will change accordingly.

### 1.1 Aims of research

The aim of this research is to segment some parts of digital Google maps of urban areas, and then decide which parts are most suitable for certain kinds of buildings. I will use image processing to extract different zones from Google maps, and then use color and shape information to extract the different zones.
1.2 Research Questions

- How do we segment some parts (functional zoning) in the Google maps?
- How do we find suitable building areas after finding the functional zones in the Google maps?

1.3 Background

For this background section, research has been conducted about technical descriptions about how to calculate the different shapes in digital urban Google maps. In GIS (Geographic Information Systems), urban planning such as features zoning, which are vegetation grows and industrial areas, are used, as described in [10]. Image processing is widely used for analyzing maps, such as morphological image processing, as described by Liu [16]. From the result of these papers, much can be learned about functional zoning, UHI and urban planning. After having read these papers, I have been able to develop some views and ideas, for example regarding different methods of dividing digital urban maps into functional zones.

For the concepts of functional zoning, Urban Heat Island and urban planning, I have read more than ten scientific articles, allowing me to know how different authors think regarding these concepts. These articles are presented in the next sections.

1.3.1 Previous research

Yuan et al. [17] mention the four typical functional zones in urban areas: traffic zones, commercial zones, industrial zones and residential zones. They selected typical functional areas of an urban area and performed dust sampling of the streets in these areas. In their analysis, the dust showed traces of heavy metal pollution. They also analyze the spatial differences of the pollution.

Hui et al. [13] elaborate on the analysis of the Urban Heat Island Effects of cities in China based on NOAA/AVHRR. They adjust the radiation of the 4th channel data of AVHRR. The urban heat island temperature is explained by the difference of luminance temperature between urban and suburban areas. To analyze how the temperature changes between day and night, they studied the twelve cities which stand for the largest Heat Island intensity, using digital statistics method, plane equivalent lines and three-dimensional methods.

Cui and Qian [2] mention that the UHI Effect has gradually become an important environmental problem caused by the cities. The method of Remote Sensing (RS) is becoming a more effective way of analyzing the relation between land and the Urban Heat Island Effect. They represent different temperatures by different brightness in the maps. GIS was also used in this paper to analyze the relation between the Urban Heat Island Effect and the different land types in Guangzhou City.

Xiao and Xu [3] use two distinct ETM+ remote sensing (RS) images to show the effect of UHI by converting the gray scale values of the band 6 pixel brightness to temperature. Other researchers found there is an inverse correlation between brightness temperature and vegetation using Aregis 9.3.

Lin et al. [4] propose a 3D urban planning system based on GIS and virtual reality to make urban planning more dynamic. The 3D urban planning system achieve the urban planning schemes through the use of virtual worlds – during the modeling of urban planning in the computer we can easily perform analyses of the computer models and scenes of real-time data for the real world. At the same time it also focuses on visualization technology of the urban planning and it is one of the applications in the urban planning. The 3D urban planning system can make the urban planning shown intuitively by 3D and improve the level of design in the urban planning. It uses
the techniques of GIS and VR to implement urban planning dynamically. This technique makes the urban planning more vivid and intuitive, but on the other hand, it is difficult to implement.

1.3.2 Color Model

There are many color spaces. One that is commonly used is RGB. The RGB model is used in computer graphics as a basis of a color space [1]. The primary colors of light are Red, Green and Blue – RGB. By combining these base colors, we can get almost all possible colors. The main purpose of the RGB color model is to represent and display images in electronic systems. The secondary colors are CMYK: cyan, magenta, yellow and black (for the K). CMYK are created by subtracting the primary colors from white.

![RGB and CMYK cube](image)

Figure 3. The cube about RGB and CMYK [6].

In Figure 3, we can find that the schematic of the RGB color cube represent the primary and secondary colors of light at the vertices. Points along the main diagonal have gray values from black at the origin to white at the point (1, 1, 1).

Color images usually have three matrices that build up the image, each corresponding to one of the primary colors. Knowing this, the image can be processed. The resulting processed components are combined together in order to build up the new RGB image.

1.3.3 Morphological Image Processing

Morphological image processing algorithms are used in many machine vision systems and are very powerful image processing tools. For a binary image, the basic morphological operations are dilation and erosion. Mathematical morphology uses the tools of set theory for the shape and structure [1].

In general, it uses logical expressions to perform set operation on binary images. These are defined in Table 1. They are OR (|), AND (&) and NOT (~).

<table>
<thead>
<tr>
<th>Set Operation</th>
<th>MATLAB Expression for Binary Images</th>
<th>Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>A ∩ B</td>
<td>A &amp; B</td>
<td>AND</td>
</tr>
<tr>
<td>A ∪ B</td>
<td>A</td>
<td>B</td>
</tr>
<tr>
<td>A^c</td>
<td>~A</td>
<td>NOT</td>
</tr>
<tr>
<td>A - B</td>
<td>A &amp; ~B</td>
<td>DIFFERENCE</td>
</tr>
</tbody>
</table>

Table 1. Expressions in MATLAB to represent logical set operations [5].

Morphological operations often require two operations which are specific to sets whose elements are pixel coordinates.
The reflection of set $A$, denoted $\hat{A}$, is defined as

$$\hat{A} = \{ w \mid w = -a, \text{ for } a \in A \}$$

The translation of set $A$ of points $z = (z_1, z_2)$, denoted $(A)_z$, is defined as

$$(A)_z = \{ c \mid c = a + z, \text{ for } a \in A \}$$

Figure 4 illustrates these two operations.

(a) Two sets $A$ and $B$
(b) Translation of $A$ by $z$
(c) Reflection of $B$

Figure 4. Illustrates two operations [6].

Dilation is an operation that “grows” or “thickens” objects in the binary image. Consider an image $p$ of size $n \times n$ pixels that $p = [p_{ij}], 0 \leq i, j \leq n-1, 0 \leq p_{ij} \leq 255$. Also consider a structuring element (SE) of size $m \times m$ pixels. The formula is [1]

$$p_{ij} = \max \{ p_{i+q,j+r-se_{ur}}, \mid m/2 \leq q, r \leq [m/2] \}$$

In Figure 5, if $A$ is some rectangular object in the image and $B$ is the structuring element, then the yellow area shows how much $A$ have grown in size by the dilation process.

Erosion is an operation that “shrinks” or “thins” objects in a binary image. The formula is [1]

$$p_{ij} = \min \{ p_{i+q,j+r-se_{ur}}, \mid m/2 \leq q, r \leq [m/2] \}$$

In Figure 6, if $A$ is some rectangular object in the image and $B$ is the structuring element, then the yellow area shows how much $A$ have shrunk in size by the erosion process.
For many techniques of Morphological Image Processing, the morphological closing will be very useful for my research. It is dilation followed by the erosion. This operation fills in small passages and holes.

The morphological closing processing is shown in Figure 7. The structuring element is a disk with diameter bigger than the small holes and smaller than the biggest holes.

2 Method

In this section, I will describe at first which useful images can be collected and selected. Secondly we will segment different areas from the Google map. Moreover, we will find out which areas are suitable for constructing new buildings. Lastly, we will show the suitable area to the new images.

2.1 Image Selection

I have collected the urban images from Google Maps (maps.google.com). In this paper, I only focus on the city of Gävle in Sweden. So all the maps I have selected are maps of Gävle.

In the first step, I need to segment the urban Google map into regions. For that purpose, I used an image of dimensions 762 × 462 pixels, shown in Figure 8. In this image, I have used color segmentation to extract different zones from digital Google maps.
In Figure 8 it is clearly shown that different colors represent different functional zones. The reason why I used this image is that all functional zones I have studied are included. We can try to use this as the example image and make some segmentations into functional zones. Thus, we can achieve part of the aim of this research.

After completing the first step-segmentation, I selected the other image shown in Figure 9, as it mostly consists of residential areas. For this image, the scale of the map was chosen as 200 m. The scale of 200 m is better than the scale of 500 m in my research, since the scale 200 m can show more details for the urban areas. In addition, I will choose digital urban maps with more areas space, which means more than 70000 pixels in my application. In this case, it is easier to find a suitable area for construction.
2.2 Segmentation and Image Pre-processing

In this part, we will start to segment the selected map. The functional zones I used are divided into five parts: vegetation, hospitals, universities, residential areas and industrial zones. We will show the functional zoning separately in different binary images and the white pixels in those images will display corresponding functional zones.

In the section of image pre-processing, the image is converted to a binary form and only sharp borders of buildings and roads will be shown. It is necessary to find the borders of buildings, roads, rivers and railways because we obviously cannot construct buildings on top of these things. The result of this operation is shown in Figure 10.

![Borders of building and roads.](image)

2.2.1 Color Model

In my research, I have used the RGB model space for color image processing. The RGB color model is used in color image processing by altering three channels (R, G and B). In the Google digital maps, different functional zones have their own color. Therefore, as long as we find out one RGB value in the image which contains the functional zoning, this RGB value can be used in all images.

In this part, we will find out the RGB values of different functional zones in Figure 8 – the values are listed in Table 2.

Table 2. The functional zoning of RGB color model

<table>
<thead>
<tr>
<th>Functional zoning</th>
<th>R channel</th>
<th>G channel</th>
<th>B channel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vegetation grows</td>
<td>(179 - 182)</td>
<td>(208 - 212)</td>
<td>(148 - 161)</td>
</tr>
<tr>
<td>River</td>
<td>(147 - 158)</td>
<td>(174 - 181)</td>
<td>(195 - 212)</td>
</tr>
<tr>
<td>Yellow road</td>
<td>(246 - 255)</td>
<td>(247 - 255)</td>
<td>(138 - 156)</td>
</tr>
<tr>
<td>The depth yellow road</td>
<td>(253 - 255)</td>
<td>(220 - 227)</td>
<td>(94 - 114)</td>
</tr>
<tr>
<td>Hospital</td>
<td>(226 - 231)</td>
<td>(195 - 202)</td>
<td>(188 - 198)</td>
</tr>
<tr>
<td>University</td>
<td>(217 - 226)</td>
<td>(208 - 213)</td>
<td>(168 - 176)</td>
</tr>
<tr>
<td>Industrial Zone</td>
<td>(209 - 211)</td>
<td>(207 - 208)</td>
<td>(201 - 204)</td>
</tr>
<tr>
<td>Building</td>
<td>(213 - 226)</td>
<td>(212 - 224)</td>
<td>(207 - 219)</td>
</tr>
</tbody>
</table>
The different functional zones have different colors. In the Google map, the vegetation is green, the hospital is pink, the river is blue, the university is brown, the industrial area is gray, and the residential areas are slightly darker than industrial area. The road is white and yellow.

### 2.2.2 Classification

In the last step, I have found all of functional zones in the Google map. We need to gray scale the functional zoning firstly in order to obtain the suitable and usable areas. In the previous step, we have found the RGB color space of the functional zoning. We will set those areas in black and other functional zones including buildings, roads and railways are set to white. Then we get the binary image and we will apply morphological filter as below.

### 2.2.3 Morphological Image Processing

In the image from the last step, there is still some noise. For example, we cannot see the whole buildings clearly and the areas suitable for building has much noise, so we need to reduce the noise by using morphological processing. There are many types of morphological processing – in this paper, we choose morphological closing.

For this case I want to fill the holes until the roads and buildings are airtight. As an example of explanation, I used morphological closing to solve a similar problem shown in Figure 11. The morphological closing tends to smooth the contours of objects. It generally joins narrow breaks, fills long thin gulfs, and fills holes smaller than the structuring element [5].

![Original image](image1.png)  ![Closing](image2.png)

*Figure 11. Morphological closing.*

In the original image, the white block represents a building, but there are some holes in the building. After the morphological closing processing, the holes are filled. In other words, the shape of the building and the road become more distinguished and clear. This method is useful for finding the suitable construction areas.

### 2.3 Algorithm Description

A digital image consists of pixels. The size of the image is $m \times n$. The structure of one pixel is shown in Figure 12. There are eight neighbors which are shown as the pixel in
yellow color. Besides, the boundary of pixels has less than eight neighbors which are shown in red color.

![Figure 12. A pixel and its neighbors.](image)

The pixels which are not in the boundary have eight directions: north, northwest, west, southwest, south, southeast, east and northeast, as shown in Figure 13.

![Figure 13. Eight directions.](image)

In MATLAB, a pixel \( p = (x, y) \) is the current pixel value. The point \((x-i, y-i)\) is pointing in the direction \( \circ \). We will find white points toward the top left corner. Each direction has a specific value, as shown in Figure 14.
After the morphological processing of 2.2.3, the image is a binary image in which suitable construction areas are black and the functional zoning – roads, rivers and railways – are white. The distance between the mid-point of the buildings and the white point (or the boundaries of map) should be larger than the provided value.

I will use direction  as the sample to find the suitable construction areas. The current pixel is  and find the white point by direction. There are two cases in the algorithm processing.

Case 1: If the current pixel is satisfied with the condition  and those pixel  is white. That pixel is what we want and the program will exit the loop. After that the distance will be calculated between the current pixel and the white pixel.

Case 2: If it cannot find the white pixel, it will find the boundaries of image. After that the distance will be calculated between the current pixel and the boundary pixel.

Finally, by combining these 2 cases, the suitable construction areas will be found in the image.

The formula of the distance is defined in Equation 1:

\[
\text{Distance} = \sqrt{(x - x')^2 + (y - y')^2} \tag{1}
\]

where  is the current pixel and  is the white pixel or the boundary of map.

However, it is not the suitable building distances, so we need a threshold to get the right distances. In that case, the value of threshold is defined as 15 for the map which scale is 1:200m. For the other map, I will describe in next section.

2.4 Optimization of image

For the previous processing, suitable construction areas are found, but it works only for maps in the scale of 1:200m in Google Maps. Now, we want to implement this program so that it can be used with images in different scales. Figure 15-18 show some Google Maps images of different scales.
Figure 15. The 1:500m scale map.

Figure 16. The 1:200m scale map.

Figure 17. The 1:100m scale map.
Depending on the proportion of the maps, it could calculate the multiple between the other scale map and 1:200m scales map.

\[
t = \frac{\text{other scale value}}{1:200}
\]

where \( t \) is the multiple value. For example, if the scale value of current map is 1:100, \( t \) is equal to 2.

I have set a threshold value of 15 in the scale maps of 1:200m. If we want to work by every scale maps, we need to set the other threshold which is \( 15 \times t \). If the distance is larger than this threshold, the suitable building areas space can be found.

Finally we can display the suitable construction areas on the image.

### 3 Result

In this section, I will describe my results in steps.

**Step 1: Showing Image Selection**

I choose two main maps for the original image to test my program. The original image 1 is used to segment different functional zoning. The original image 2 is used not only to segment different functional zoning but also to find the suitable building areas. It shown as Figure 19-20.

*Figure 18. The 1:50m scale map.*

*Figure 19. Original image 1.*
Step 2: Segmentation of the functional zoning in the original image. Based on the original Figure 19, the different functional zoning was segmented and obtained at each image, showed in Figure 21-24.

As the result of Figure 25, we just segment only Industrial Zone in one image at the program, and the program will print out the result which functional zoning have not found at this image.
The Command Window output:
>> Segment('map1.jpg')
This image doesn’t have vegetation grows!
This image doesn’t have hospital!
This image doesn’t have university!

Step 3: In Figure 26, the areas which are not suitable for new buildings will be found – those pixels will be set to black. It means the black areas are not suitable building areas. The road, river and railway are also black. The result is showed in Figure 26.
Step 4: After the RGB image is obtained, we perform the classification step, it means we set the those areas in black and other functional zones including buildings, roads and railways are set to white in which the RGB image becomes a gray scale image. The result is showed in Figure 27.

![Figure 27. Gray scale image.](image)

Step 5: Transform the gray scale image to the binary image. Then, process it by morphological closing. Most of the noise will be reduced. The black pixel areas are the places which may be suitable for constructing new buildings. The result is showed in Figure 28.

![Figure 28. Morphological closing.](image)

Step 6: The suitable building areas can be found after running the algorithm of the program. The blue areas represent the suitable building areas. In other words, we can construct new buildings in the blue areas. The result is showed in Figure 29.
Step 7: Optimization of image, this step is optimize the step 6, based on the multiple of different scale maps. No matter the scale values of the maps, the suitable building areas will be found. The blue color spaces are the suitable building areas in 1:100m and 1:50m scale maps. The result is showed in Figure 30-31.
4 Discussion

At the beginning, I used HSV color space to find the functional zoning color. However the result was very bad. The boundaries of the functional zoning were not clear. It is hard to find a good threshold for HSV. I then found a principle of Google Maps that each functional zone has a specific, solid color. No matter which Google map I used, these colors stayed the same. Therefore, I have used the RGB color space.

In this paper, I have segmented the maps into the five main functional zoning areas which are Vegetation grows, Hospital, University, Industrial Zone and Residential area. However, the number of functional zones is much larger than only these five. Because of this, there is a limitation of the segmentation of all the functional zoning in the Google maps. So it is the shortcoming in my program such as it just only segment five functional zoning.

Because of the road names written in Google Maps, the colors of functional zoning areas have holes. The morphological closing filter is a good choice to solve this problem by filling the holes.

After finishing the entire image processing, the suitable building areas were found in the Google maps. However, sometimes I found that the suitable building areas also include the road. In other words, the building might be built on the road! When I found this problem, I improved my program. I included roads, railways and rivers when segmenting into the functional zones. It is the advantage in my program because the program thinks about the road, river and railway, the suitable building areas cannot build at those areas. When the Google maps test in my program, the program will automatic found the road, river and railway, then forbid those areas build the construction.

Although the result of finding the suitable areas space is correct, we should pay more attention to the efficiency of the program. The program is very time consuming. It only calculated eight directions, but the running time need several seconds. When I chose the smaller scale of the image, the running time became much longer. In further work, the calculations will need to be done in more directions. At that time, figuring out how to improve the running speed will be necessary. I suppose it may be related with the calculation of the distance. When the current pixel hits the white pixel or the boundaries of the maps, the distance can be calculated – after that, compare the result
with the shortest distance. So finding the pixel takes too long time. A threshold on the
distance can be set. When the distance becomes larger than this threshold, simply stop
comparing the distance. But in this case, the suitable building areas may be smaller
and incomplete.

The second issue needs to be discussed that I found the suitable pixel to build the
building. When I use the suitable pixel to calculate the rectangle for the house, the
running time is too long and sometimes draws it incorrectly, even on top of roads. I
spent a lot of time debugging, but was unable to solve this problem. More research
will be necessary for this.

The third issue needs to be mentioned that I can optimization of Google maps
which are different scale maps, then found the suitable building areas at different scale
maps. In other word, No matter which scale maps I test in the program, I can found the
suitable building areas. However, the weakness in this part is the program cannot
automatic calculation the multiple between the base scale maps and the current scale
maps. It need to implement the other algorithm to improve this weakness.

5 Conclusion and Further work

To sum up, this algorithm will help to plan for new buildings in urban areas. For the
planner it could help to find suitable construction areas for new buildings. At the same
time it could be important the planner to know if there are different functional zoning
in the areas of further building.

The application in this paper consists of two parts. The first part is segmentation
and image pre-processing. The other part is finding the suitable building areas in
Google maps – the blue color areas resulting from the application are the suitable
building areas.

In the first part, it segments different functional zoning in the Google maps such as
Vegetation grows, Hospital, University, Industrial Zone and Residential area. The
segmentation of regions depends on the different colors from the functional zoning. It
uses the RGB color space to extract these functional zones. After that, morphological
closing is used to fill the holes and find the boundaries of roads in the binary image of
Google maps.

The other part is finding the suitable building areas. This can help people decide
find which areas are suitable for constructing new buildings, and which are not – if an
area is not suitable, it is unnecessary to spend time analyzing this area. This algorithm
can therefore help people save time, and thus, money. This algorithm needs to set
eight directions and calculate the distances in the maps. Finally it can get the result of
suitable building areas. In addition, I was able to do some optimizations of the
algorithm, in that it can find the suitable building areas at different scales of Google
maps.

For further work I suggest the following:
• Using RGB color space finds the colors of all of the functional zoning at the
Google maps. After that we can segment all the functional zoning in the urban maps.
• Calculate more directions in the maps. By calculating these directions, the
algorithm can become more accurate and the distances we calculate more correct.
• Find the free wind path and detect it in Google maps. Through analysis of these
aspects, we may avoid to build tall buildings in unsuitable areas, thus reducing the
influence of the Urban Heat Island Effect.

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References


