URBAN LAND COVER ANALYSIS FROM SATELLITE IMAGES

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ABSTRACT

This is a study of modeling urban environments from TM satellite images. Urban environments are so heterogeneous. It is necessary to simplify them as combinations of basic land cover materials in order to enable quantitative studies. The V-I-S model proposed by Ridd in 1995 is a conceptual model to simplify urban environments as combination of three basic ground components: vegetation, impervious surface, and soil. Most urban grounds can be interpreted as combinations of these three basic components. This model is used by this study on Salt Lake City, Utah. As a step further, six ground components are selected as basic components of urban environments: two for vegetation, three for impervious surface, and one for soil. Percentages of these six ground components are extracted from a previously developed supervised classifier. Various charts and plots are generated to demonstrate the capacity of V-I-S composition on urban land cover analysis. Nine general urban features are selected and V-I-S composition extracted. Examinations of the V-I-S composition may reveal that most urban features have their own unique V-I-S composition, which is difficult to observe from satellite image or per-pixel classification methods. These unique V-I-s compositions may be a key factor for further urban land cover analysis.

INTRODUCTION

Satellite imagery has been a useful tool for monitoring environments since early 70's when MSS provide the first commercial satellite image. In the past three decades, the remote sensing community and other disciplines witnessed remarkable improvements in satellite image quality and quantity, in terms of spectral resolution and spatial resolution. With these improvements in satellite images, along with the progresses in digital image processing algorithms, opportunities exist to do environmental quantitative analysis, rather than just land classification or object identification.

Unfortunately, some problems reported decades ago remain unsolved, especially in urban areas (Forster, 1985). The most significant problem from remote sensing of urban areas is mixed pixels (Card, 1993; Wang, 1990a; Wang, 1990b). Mixed pixels refer to pixels with more than one land cover material within it. They are caused by various factors. One of them is the ground heterogeneity. Imagine the heterogeneous urban landscape and fit them into satellite image pixels. For example, a TM image pixel size is 30 * 30 meters. It is very difficult to find an area this size with only one land cover material within it. It is inevitable to have mixed pixels on urban remote sensing. How to handle them may be a key factor to the success of any urban remote sensing research. Fuzzy representation may be a solution. In addition, there is a need for a model to simplify heterogeneous urban environments so that they could be represented by a limited number of end members, and quantitative analysis could be performed.

THE V-I-S MODEL

Ridd (1995) proposed the V-I-S (Vegetation-Impervious surface-Soil) model for studying urban morphology by examining TM satellite images and aerial photography of the Salt Lake City metropolitan area. It is a conceptual model to simplify heterogeneous urban areas to simple combinations of basic ground components, namely vegetation, impervious surface, and soil three basic cover components. It is proposed as a fundamental theory, as well as a method, to examine land cover types in urban areas. The central idea of the V-I-S model could be explained by a V-I-S diagram (Figure 1). In this diagram, each axis represents one component. Values along the axis indicate the percentage of that corresponding component. Taking medium-density residential in Figure 1 as an example, projecting it to vegetation axis yells 45%, projecting it to impervious surface axis yells 40%, and projecting it to soil axis yells 15%. Therefore, medium-density residential is said to be a possible combination of 45% of vegetation, 40% of impervious surface, and 15% of soil. However, This is only an approximate estimation. As a matter of fact, each land use type yells a range, not a point in the V-I-S diagram. That is, general urban features can be represented as a set of combinations of V-I-S components within certain threshold.

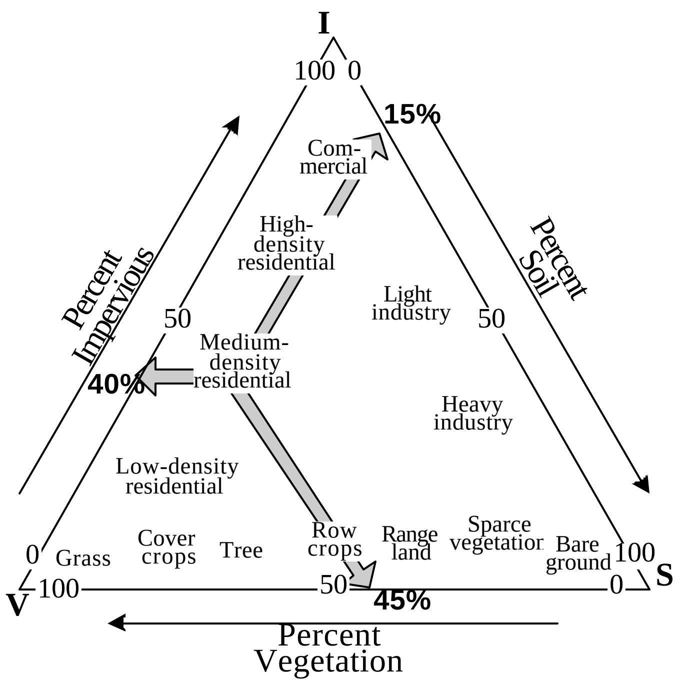


Figure 1. General urban features in a V-I-S diagram.

THE V-I-S COMPONENT PERCENTAGES

The data used in this study is a 1990 TM image of partial Salt Lake City area. However, the TM band 6 was dropped out because of coarse spatial resolution. A previously developed supervised classifier was applied to it. This classifier involved fuzzy classification and expert systems (Hung, 2001). The resultant image is not a per-pixel classification image. Instead, it is a six-channel image with each channel indicating the percentages of one pre-defined land cover type. It demonstrated a significant relationship between the estimated ground component percentages and surveyed ground component percentages, which is derived from visual interpretation of aerial photography.

Define Ground Components

This research is based on the V-I-S model. As a step behind, six ground components are selected as basic ground cover types in urban areas. They are: healthy green grass vegetation (V_gr); tree and/or shrub vegetation (V_tr); bright impervious surface (I_br), such as rooftop, metal, and tile; medium impervious surface (I_md), such as concrete and weathered asphalt; dark impervious surface (I_dr), such as asphalt and darkened concrete; and soil and/or dry vegetation (S_dv). Soil and dry vegetation are put together as one component because these two land cover types are quite similar in their spectral reflectance characteristics, as well as the brightness values from satellite images (Hoffer, 1978). The V_gr component could be easily found in golf courses. The V_tr component could be found in residential areas, especially low density residential areas. The I_br component could be found on large buildings. The I_md component could be found in commercial or industrial areas. The I_dr component could be found on transportation networks. The S_dv component could be found on foothills. Table 1 and Figure 2 shows the mean brightness values of these six ground components.

Table 1. Mean brightness values of the six ground components.

Comp.	B1	B2	B3	B4	B5	B7
V_gr	66	34	29	149	103	32
V_tr	64	28	26	84	64	25
I_br	143	76	95	86	129	78
I_md	103	48	56	51	80	51
I_dr	81	34	38	33	53	34
S_dv	80	39	52	66	113	56

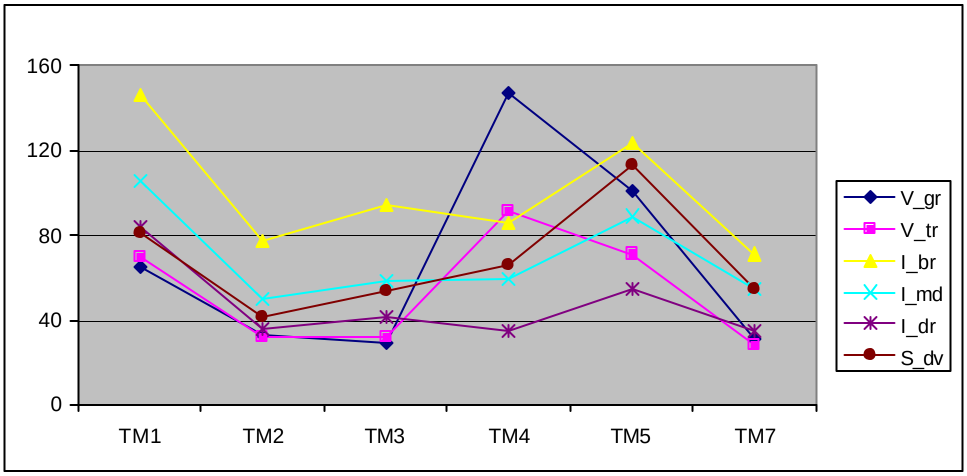


Figure 2. Mean brightness values of the six ground components in a line chart.

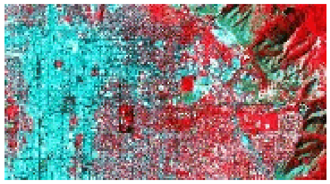
Resultant Percentage Images

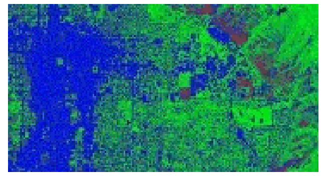
Figure 3 shows the TM image and the classified images. Figure 3(a) shows the TM image with false color (R:B4, G:B3, B:B2). Figure 3(b) shows the V-I-S percentage with false color (R:soil, G:vegetation, B:impervious surface). Figure 3(c) through Figure 3(h) shows all the single component percentage images (V_gr, V_tr, I_br, I_md, I_dr, and S_dv, respectively). Lighter tone indicates higher percentage, and vice versa. As mentioned earlier in defining ground components and as one can expect, areas with high V_gr percentage are golf courses and parks. Areas with high V_tr percentage are mainly on residential areas and mountainous areas. Areas with high I_br percentage are individual large buildings. Areas with high I_md percentage are mainly on commercial areas and industrial areas. Areas with high I_md percentage are transportation networks. Areas with high S_dv percentage are mountain foothill and unused lands.

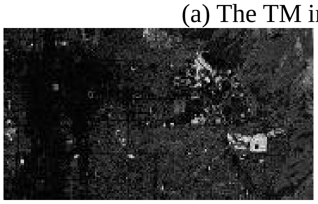
URBAN LAND COVER ANALYSIS

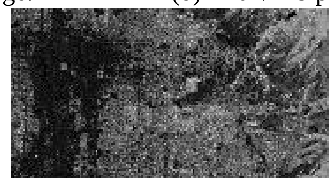
To demonstrate the capacity of using the V-I-S component composition on urban land cover analysis, several general urban features were selected from TM image, and V-I-S composition extracted and drawn on a V-I-S diagram. These general urban features are a golf course, a city park, low-density residential areas, medium-density residential areas, high-density residential areas, commercial areas, industrial areas, university campus, and mountain foothill. Figure 4 shows these urban features on the TM image of the study area. Table 2 and Figure 5 show the V-I-S composition of these urban features. Figure 6 is the V-I-S composition of these urban features in a V-I-S diagram.

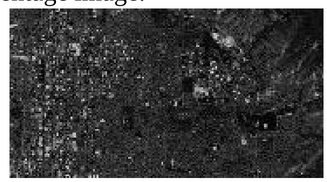
Though these urban features are shown in the TM image, it is not very easy to identify them one by one, or to distinguish from each other, without prior information of the study area. However, as one can observe from Table 2, Figure 5, or Figure 6, each urban feature has their own unique V-I-S composition. It is so unique that one might draw territories according to the V-I-S composition, and assign these territories to general urban features, as shown in Figure 1. However, it has to be emphasized that these data are for general urban features, there are always some extremes or exceptions. One can not use only one model and try to cover all possibilities in the real world, especially in the heterogeneous parts of the real world.

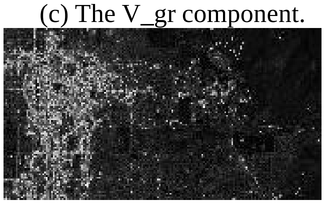

(a) The TM image.

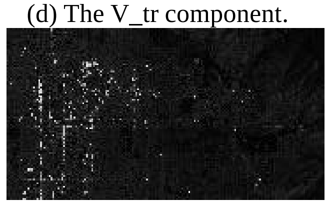

(b) The V-I-S percentage image.


(c) The V_gr component.


(d) The V_tr component.


(e) The I_br component.


(f) The I_md component.


(g) The I_dr component.

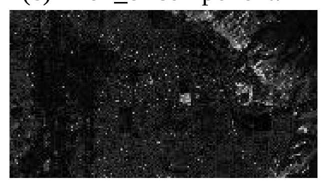

(h) The S_dv component.

Figure 3. The TM image and component percentage images.

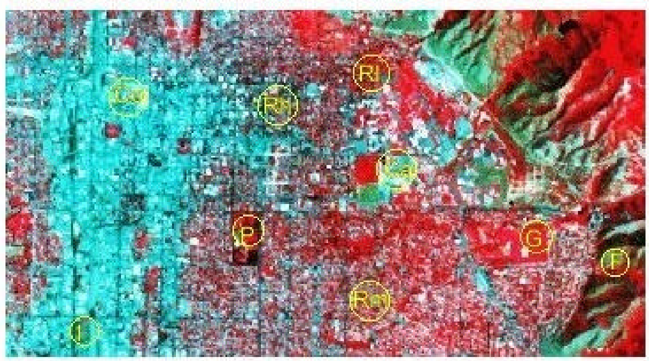


Figure 4. Selected urban features for land cover analysis.
G: glof course. P: city park. Rl: low-density residential area. Rm: medium-density residential area.
Rh: high-density residential area. Co: commercial area. I: industrial area. Ca: university campus. F: foothill/soil.

Table 2. V-I-S percentages of selected urban features.

	V %	I %	S %
1. golf	93.6	5.6	0.8
2. park	68.9	25.8	5.3
3. res_l	69.3	23.9	6.8
4. res_m	55.8	33.5	10.8
5. res_h	42.6	45.8	11.6
6. comm	10.0	86.0	4.0
7. indu	26.4	49.2	24.4
8. campus	45.2	43.2	11.6
9. soil	14.7	21.1	64.1

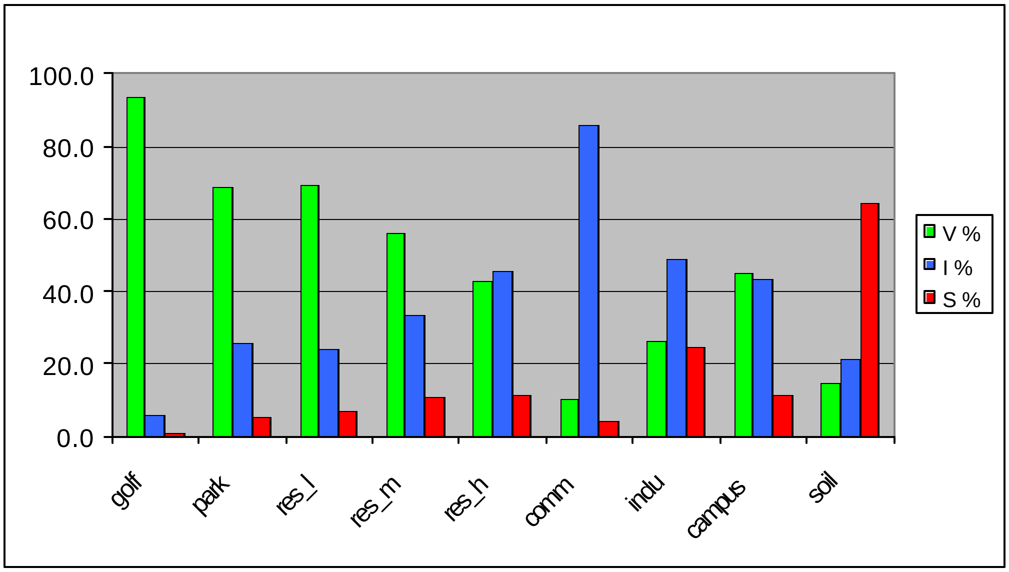


Figure 5. V-I-S percentages of selected urban features in a bar chart.

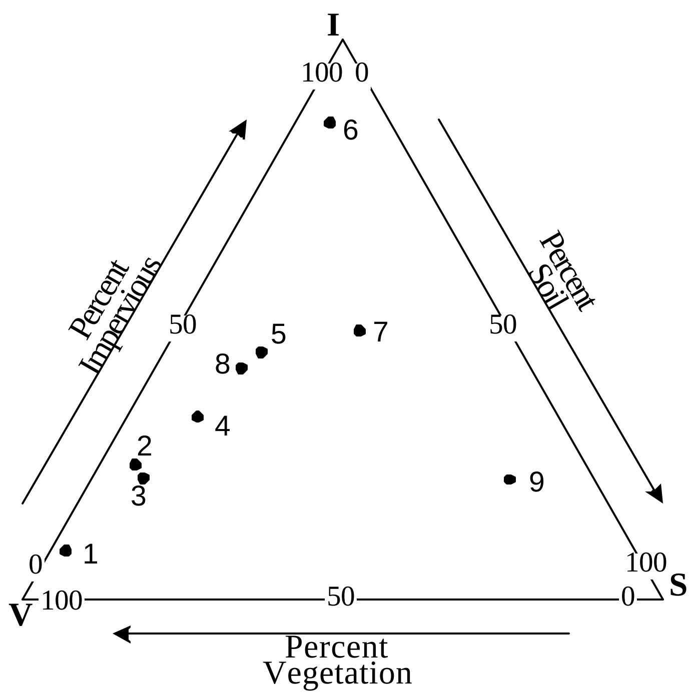


Figure 6. V-I-S percentages of selected urban features in a V-I-S diagram.

An impressive point one can observe from figure 6 is that residential areas with different densities could be easily identified and distinguished from each other. High-density residential areas refer to areas with big resident buildings and small amount of vegetation, such as apartment complexes. They could usually be found around downtown or early-developed residential areas. Medium-density residential areas refer to areas with single housing units and moderate amount of vegetation. Most of the residential areas are found to be in this category. Low-density residential areas refer to areas with individual housing structures and large amount of vegetation coming from big backyards or front yards. In this study, it has been demonstrated that they all have their own unique V-I-S composition that could be used to distinguish from each other.

However, it is a little confusing between a city park and low-density areas, or between high-density residential areas and university campus. These confusions may come from the differences between the literal definitions of land-use and land-cover types. Land-use areas refer to what this land is used for, such as commercial areas, industrial areas, or residential areas. Land-cover materials refer to what is actually on the land, such as grass, asphalt, or soil. These selected urban features are land-use-oriented types. The V-I-S model is land-cover based. The relationship between land-use and land-cover is not one to one. It means that different land-use areas may have the same land-cover materials and composition. Low-density residential areas and city parks might be a good example for this.

CONCLUSION

The resultant image provides subpixel information about V-I-S components of urban areas. By this representation, heterogeneous urban areas are simplified to combinations of basic ground components. Various urban land cover types can be displayed on a V-I-S diagram, as shown in figure 6. Therefore, urban studies can be conducted not only in a quality way, but also in a quantity way. The resultant image contains considerable biophysical information that is not usually extracted from satellite images with per-pixel classifier. It can prove useful in various urban studies, such as population studies, runoff modeling, air pollution analysis, urban forest research, urban growth, and urban change modeling.

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