DETECTION OF AREAS FOR RAINWATER HARVESTING USING AIRBORNE LASER SCANNER AND AERIAL IMAGERY

Jorge Antonio Silva Centeno[1], Regina Tiemy Kishi[2], Edson Aparecido Mitishita [1]

1 : Geomatics Department
{centeno}{mitishita}@ufpr.br
2 : Hydraulics and Environmental Sanitary Engineering Department
rtkishi.dhs@ufpr.br
UFPR Federal University of Paraná, Po.Box 19011, 81531-990, Curitiba, Paraná, Brazil

Résumé

Cet article présente une méthode d'identification des toits pour la récupération des eaux pluviales, basée sur l'utilisation des données d'un laser à balayage et d'imagerie visible et proche infrarouge. La discrimination automatique des surfaces couvertes de végétation et de toits s'avère difficile lorsque seule la hauteur des pixels est utilisée ; la procédure s'améliore lorsque la variation locale de l'altitude, c'est-à-dire la texture, est analysée. L'image obtenue par balayage laser est d'abord seuillée en fonction de la hauteur. La morphologie mathématique est également utilisée pour sélectionner les plus grandes surfaces, plus propices à la récupération des eaux pluviales. Lorsque la densité du nuage de points est trop faible, l'analyse conjointe des données laser et des photographies aériennes permet une meilleure discrimination de la végétation et des toits. L'étude démontre la viabilité d'une utilisation conjointe du laser à balayage et de la photographie aérienne pour une telle application et la puissance de l'analyse texturale pour la discrimination.

Mots clés : télédétection, lasergrammétrie, traitement d'images, recueil d'eau pluviale.

Abstract

This paper describes a methodology for the identification of roofs for rain water harvesting, based on the use of laser scanner data and VIS/NIR imagery. Automatic discrimination of areas covered by vegetation and roofs is not an easy task when only information of pixels height is used; the procedure becomes more friendly when the local variation of the height, like the texture, is analyzed. First, the laserscanning image is thresholded according to the height. Mathematical morphology is also used to separate the largest surfaces, more suitable for rainwater harvesting. When the density of the point cloud is too low, the integrated analysis of laser scanning data and aerial photographs proves to allow a better discrimination of vegetation and roofs. The study shows the viability of the use of laser scanning data and aerial photographs for this purpose and proves that the analysis of texture is a powerful tool for discrimination purposes.

Keywords *: remote sensing, laser scanner, image processing, rain water harvesting.*

Resumo

Esse artigo apresenta uma metodologia para a identificação de telhados para recolher água da chuva, com base no uso de dados de um laser escaner e de imagens no visível e infravermelho. A discriminação automática de áreas cobertas por vegetação e telhados sofre dificuldades quando a elevação dos pixels é a única fonte de informação utilizada. O procedimento é melhorado ao utilizar a variação local da elevação, ou seja, a textura. Primeiramente, a imagem obtida pelo laser é segmentada com o critério da elevação. A morfologia matemática também é utilizada para isolar as maiores superfícies mais adequadas para recolher água da chuva. Quando a densidade da nuvem de pontos é baixa demais, a análise integrada dos dados de laser e das fotografias aéreas proporciona uma melhor discriminação da vegetação e dos telhados. O estudo mostra a viabilidade do uso do laser escaner e da fotografia aérea para semelhante aplicação e conclui que a análise de texturas é uma ferramenta poderosa para discriminação.

Palavras-chave *: sensoriamento remoto, laser escaner, processamento de imagens, recolhimento de água da chuva.*

1. Introduction

Water is recognized as a limited natural resource and a public good fundamental for life and health. It has economic value and therefore fees are paid for its use, for example in industry or for domestic supply. Within the current scarcity, especially in semi-arid regions like the Northeast of Brazil, where the distribution of the precipitation is not uniform along time, the use of rainwater is a simple practice that is economically interesting within the National Politics of Water Resources.

Rain scarcity is also a serious problem in urban regions, where a possible solution is to capture rainwater for some domestic uses. This solution offers two advantages; the first one is related to the time delay that is introduced in the surface flow peaks caused by high impervious rates. The second one is the reduction of drink water supply. Rain can be harvested from impervious areas, like roofs or yards. Part of the water that would normally flow into the drainage net can be stored for a posterior use.

An adequate policy for rainwater use needs the knowledge about the available surfaces and the risk that each surface can introduce into the water quality. Within this context, we present a study aimed at evaluating the use of airborne laser scanner and visible/near-infrared imagery for the detection of surfaces that can be used for rainwater harvesting in urban areas.

2. Methods

The physical and chemical properties of the objects and their interaction with rain water impose limitations or their use for rain water harvesting. Many available alternatives are suitable for rainwater harvesting: roofs, yards and streets. Paved yards and streets discarded are in our study because they are often covered by heavy metals and synthetic oils that derive from traffic. Such pollutants limit the use of rainwater for many uses and would demand expensive treatment. We therefore focus on large roofs that are present in urban areas.

In order to choose the proper methodology, it is necessary to define a conceptual model of the desired surfaces according to the available data. In an aerial image a roof appears as 2-dimensional homogeneous region. Considering a laser scanning survey, a 2D½ model of roofs is suitable, which is enough for the purpose of the present study. Roofs for rainwater harvesting are, in a simplified model, composed by uniform planes above the earth surface and have a minimum area in order to be economically suitable.

We use a pixel based approach. Therefore, a grid was first produced from the point cloud. Laser scanning data are not uniform in space, because of the scanning pattern and distortions introduced by the relief. To build up an altimetry grid, the point cloud was projected onto a grid with a previously defined pixel size. Being $X=(x,y)$ the planimetric coordinates vector of each point, and X_0 the upper left corner of the grid, the pixel coordinates in the grid are:

$$X = (X-X_0)/\text{pixel\_size} \qquad (1)$$

More than one point can fall into the same pixel because of the scanning pattern of the laser scanning survey. In this case, it is reasonable to store the minimum height, in order to avoid mixed measurements at the borders of the objects and to enable the extraction of the terrain. It also happens that some pixels remain unfilled. The next step is to fill the blanks, using the minimum value of all neighbours with valid data. Occlusion may also cause larger unfilled regions. Therefore an iterative process is necessary to obtain a complete surface model.

The computed grid is a model that includes the terrain and other visible objects above on its surface, a so called Surface Model (SM). Two new models can be computed from the SM. The first one is the Terrain Model (TM) that is interpolated only from points that fall on the ground. Therefore it is necessary to separate the ALS points that fall on the ground from those that meet roofs, trees or other objects above the surface, which is not a trivial problem. A review of computation methods is available in the literature (e.g., Sithole and Vosselman, 2004). The algorithms aim at the classification of laser scanner points in two groups, “terrain” and “others”. A well known approach is available in the *Terrascan* software. It performs a recursive search in the point cloud locating the local minima. It is assumed that if a point belongs to the terrain it should be the local minimum. The next step is to increase the model by adding new points that satisfy criteria defined according to the relief. The decision considers the distance from the point to the current surface and the slope angle that it forms with the points already included in the TM. In an iterative process, new points are added until no more addition is possible. Points that belong to objects like buildings and trees are not included because they form step angles with the terrain surface.

As Weidner (1996) states, the difference between an original surface model (SM) and the approximation of the topographic surface (TM) contains the information about the height of buildings and trees. The difference leads to a new model, the so called Normalized Surface Model (NSM), where only the elevation above the reference surface (terrain) is stored.

Considering the geometry of buildings it is expected that a roof has high values in the NSM and a minimum height of 2 meters is reasonable to separate them from the ground and other lower objects, like cars. The problem is that such a threshold also includes pixels that belong to other objects like trees. Isolated pixels are also present, giving a noisy appearance.

The regions in the resulting binary image were smoothed and separated using morphologic operators like opening and closing. Opening was used to separate adjacent regions and eliminate isolated pixels or very small regions. Closing was used to remove blanks within the regions.

After this morphological step, we selected regions larger than the expected minimum area of buildings, considering that small roofs are not interesting for rainwater harvesting. The connected components approach, described in (Haralick and Shapiro, 1992), was applied and the area of each region was computed to remove small areas.

Segmentation

Two examples of segmentation techniques are described here. In a first approach, we used only the altimetry grid to detect and segment the roofs. In the second one laser scanning data and imagery are combined.

Altimetry data analysis

In this example it is possible to discriminate objects based on the texture of the surface because the laser scanning point cloud density is very high. Knowing that the surface of roofs is smooth, while the top surface of vegetation is irregular, the local texture within the clusters was analysed. Therefore, we computed the local gradient for all pixels within each region applying the Sobel operator.

The Sobel operator is a non-linear filter used to detect edges based on the analysis of the local gradient within a moving window. For this purpose, two filters are applied in sequence: the first one estimates the gradient in the vertical direction and a second one in the horizontal direction. The result of both filters is then combined to obtain the estimate of the local gradient, according to Equation 2. Figure 1 displays the two basic filters. Being H and V the computed value for each filter, the gradient of the region is computed as follows:

$$G = (H^2 + V^2)^{1/2} \qquad (2)$$

1	2	1
0	0	0
-1	-2	-1

(a)

-1	0	1
-2	0	2
-1	0	1

(b)

Figure 1: Sobel basic filters.**(a)** Vertical gradient. **(b)** Horizontal gradient.

The Sobel operator gives a value for each pixel. Because we are dealing with regions, a unique value was computed for each region taking the mean of the gradient of all its pixels. This value was used to classify the segments according to the texture variation. Regions with lower values, bellow 4.0, were classified as roofs, while higher values were classified as vegetation.

Figure 2 shows the roofs that were obtained using this approach. The region covers part of an airport, where big roofs are available for rainwater harvesting. The results show that it is possible to detect isolated buildings for rain water harvesting, even when vegetation is present.

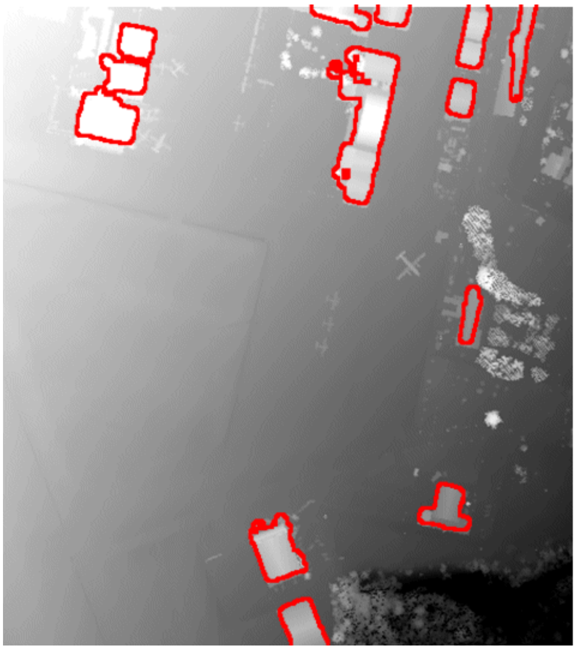

Figure 2: Segmented areas for rainwater harvesting – Airport.

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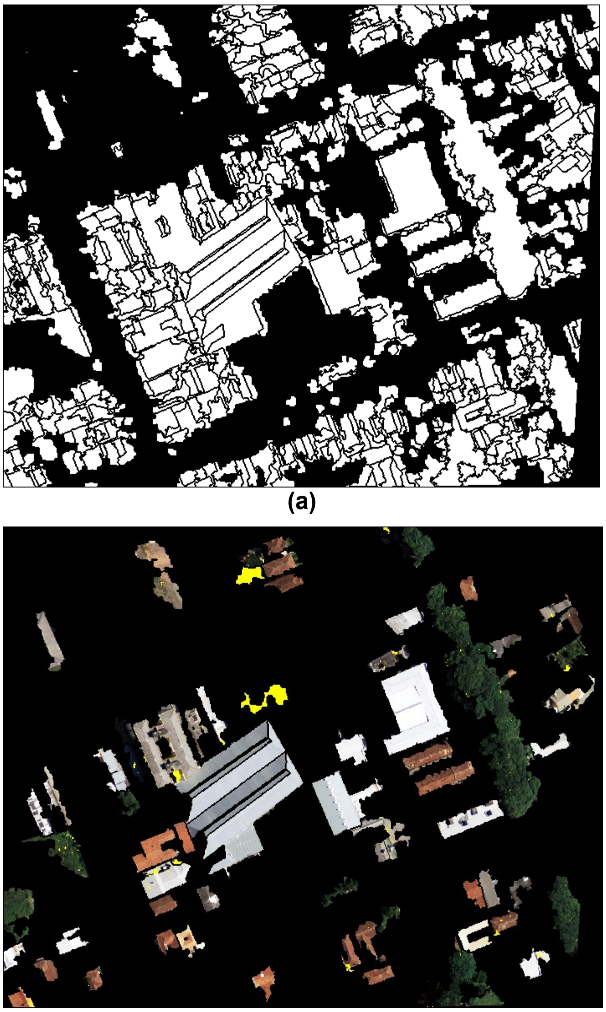
Laser scanning and imagery

The dataset of the second example covers a high density urban region, with building of different sizes. The core data for the experiment are taken from airborne laser scanning data and high resolution aerial photographs. The data were provided by *Esteio Engenharia e Levantamentos* and cover the urban region of Curitiba, southern Brazil.

The laser scanning data were acquired by an Optech ALTM 2025 scanner. The average distance between points on the surface is about 1.4 m and the average point density 1.6 pts/m^2. It must be pointed out that the density of the point cloud has to be compared to the size of the objects of interest, in order to capture enough points to describe the surfaces.

The use of high spatial resolution imagery is necessary because of the spatial variability of objects within an urban scene and its compatibility with the density of a laser scanning survey. The aerial photographs were obtained using a Cyber Shot DSC-s40 camera. Orthophotos were generated from the images. The pixel size of the orthoimages is 40 cm.

There are strong differences between the available datasets, image (raster) and laser scanning cloud point (vector). They are complementary but also demand care in the processing step. Laser scanning data are not uniform in space. The edges that limit a roof are well defined in the aerial photographs, because they have a smaller pixel size. Because the laser scanning survey is not regular and the distance between points larger, the edges are not uniform and poorly defined in the laser scanning point cloud.



(a)

(b)

Figure 3: Thresholded image containing higher objects in **(a)** a binary image, and **(b)** a colour photograph.

To build up a common geometric basis, the point cloud was projected onto a grid with the same pixel size as the orthophoto, according to Equation 1. It was necessary to fill blanks in the resulting grid, because of the irregular spacing of the laser scanning survey. This was done by using mathematical morphology operators.

Because of the relative small pixel size of the aerial photographs, it was decided to look for the boundaries of the objects in the multispectral imagery. For this purpose we applied the Mean Shift Segmentation algorithm (Comaniciu and Meer, 2002) available in the EDISON (Edge Detection and Image SegmentatiON) software developed by Christoudias, Georgescu, and Meer (Christoudias et al., 2002).

The mean shift algorithm considers the feature space as an empirical probability density function. If there are uniform regions within the image, their values would build up clusters in the feature space and would correspond to local maxima of the probability density function. The approach aims at locating such maxima in an iterative search process.

Figure 4: Trees (dark areas) separated from buildings (light grey) using the vegetation index.

As described in (Lee et al., 2010), the neighbourhood is defined by its centre, which initially corresponds to the position of the pixel under analysis, and a search radius. The hypothesis to be verified is if the centre of the region is the local maximum. In order to verify the hypothesis, the algorithm computes the mean of the point set in the feature space (centroid) and compares it to the centre. If they are different, then the centre is moved to the centroid and the process repeated until they coincide. This allows to shift the neighbourhood to a denser region of the dataset in each iteration. After the search process, the pixel receives the colour of the maxima. Because the process is repeated for each pixel, many similar pixels will be grouped under the same colour, building a region. The mean shift algorithm seeks the "mode" or point of highest density of the data distribution and each point within the defined radius of the trajectories that converges to the same location belongs to this segment.

In the next step, the elevation model was used to compute the terrain model and compute the normalized surface model of the region. In this model, buildings and trees are present. Using the normalized model, segments that potentially belong to buildings and trees were separated in the segmented image, obtaining a simpler image without the elements on the ground. The size of the objects was also considered to discard small roofs. Figure 3a shows the segmented image after thresholding lower and higher segments. Figure 3b displays the larger segments with the texture derived from the aerial image. Vegetation and roofs are visible.

$$V.I. = (NIR - VIS) / (NIR + VIS) \qquad (3)$$

In this case it is not possible to discriminate the surfaces based on the texture, because the spatial resolution of the laser scanning data is too coarse and vegetation areas appear smooth on the grid. The solution was to use the aerial photographs to separate vegetation from roofs by classifying the image using the Minimum distance classifier. The result obtained from the approach applied to one block of the study region is displayed on Figure 4.

Finally, only larger roofs were selected, as displayed on Figure 5. Those larger roofs offer catchment surfaces larger than 200 m^2 so that they can be used for rain water harvesting. The estimated area of each surface was also computed. This estimate is not accurate, because of errors in the segmentation step. Nevertheless, the size estimate is sufficient for the application. The problem is that some roofs were not identified, as for example the one marked with an arrow on Figure 5.

Figure 5: Segmented roofs (black) in the urban scene.

Considering the temporal distribution of rain in Curitiba, as displayed in Figure 6, it is possible to compute the potential water that can be stored each month. For example, in August which is the driest month in Curitiba, the total rain is 67.5 mm. Using the largest roofs of the considered block (total area of 4.863 m^2), it would be possible to harvest 287.6 m3 in the driest month, according to the method proposed by the Brazilian norm (ABNT 2007) shown in Equation 4. Considering 0.2 m^3 as the daily mean volume that a human being consumes, the harvested volume could cover the necessity of 48 persons.

$$V = C \cdot A \cdot P \cdot \eta \qquad (4)$$

where :

V = water volume (m^3);
A = catchment area (m^2);
P = monthly precipitation (m/year);
η = efficiency factor. It is used to express the losses in the capture and storing process and other inefficiencies.

C= runoff coefficient. For roofs, a runoff coefficient of 0.9 was used, according to (Schatzmann et al., 2009).

Because the surfaces that are used for rain harvesting are exposed to the environment they accumulate toxic substances during the dry periods (Goncalves et al., 2006) and a small amount, about 1 liter/m^2 of the first rain should not be stored or used. The discarded amount also washed the surface. Rain water cannot be directly consumed by human beings because of its low water quality. Nevertheless, it can fulfill less noble demands, like pavement washing and garden irrigation.

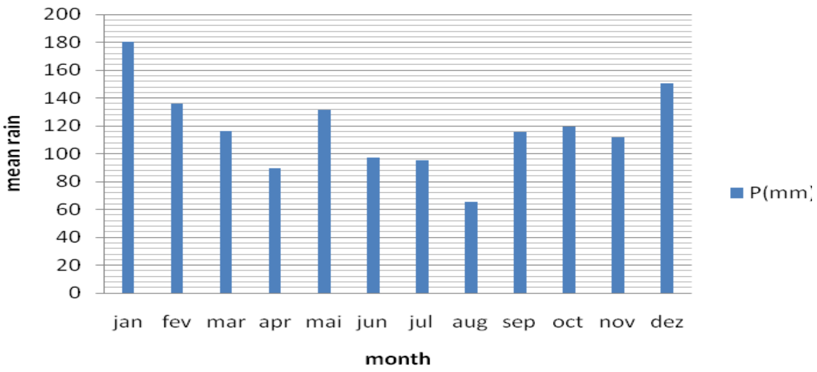


Figure 6:
Mean monthly rain in Curitiba (PRADO VELHO - UCP (02549075, 1981-1997). Source: ANA/Brazil.

3. Concluding remarks

Water supply is one of the main preoccupations of municipalities, in terms of quality and quantity. Some Brazilian cities, like Curitiba in Southern Brazil, have already introduced laws to rationalize water consumption. Rain water harvesting is economically interesting considering the high demand of modern society. This paper describes a method to identify surfaces for rain water harvesting using remote sensing data as laser scanning points and digital imagery.

The study proved that it is feasible to use laser scanning and aerial photographs to select the most suitable surfaces, considering their size. In the following studies we are applying the idea to select suitable surfaces considering also the material, because some materials are considered dangerous for human health, as for example the asbestos cement roofs that can cause cancer.

The experiments show that, when the density of a laser scanning survey is high enough, roofs can be mapped using only laser scanning data, based on the local texture of the selected surfaces. When the point cloud has low density this approach is not feasible, because the resolution is too coarse to describe the altitude variations within a tree. In such cases, the use of aerial photography is important, because it allows discriminating between trees and roofs. The segmentation step allows identifying the larger roofs that are economically more viable. As a result, a map containing the most suitable surfaces can be produced that can help decision makers to better analyse the alternative of rainwater harvesting. With the improvement of image pixel size and laser scanning point density, the perspective is to improve this identification and also increase the study, by adding more information, such as a better description of materials, using hyperspectral data, and a more realistic and accurate description of the geometry of the roofs.

References

ABNT. 2007. ABNT/CEET-00.001.77 2º PROJETO 00.001.77-001. Aproveitamento de água de chuva de coberturas em áreas urbanas para fins não potáveis – Requisitos.

Comaniciu, D., Meer, P., 2002. Mean shift: a robust approach toward feature space analysis. IEEE Transactions on Pattern Analysis and Machine Intelligence 24(5), 603-619.

Christoudias, C., Georgescu, B., Meer, P., 2002. Synergism in low-level vision. In: International Conference on Pattern Recognition, Quebec City, Canada, vol. IV, pp. 150-155.

Gonçalves, R.F., Philippi, L.S., Vaccari, K.P., Peters, M.R., 2006. Aproveitamento da Água de Chuva. In: Gonçalves, R.F., coord. Uso racional de água em edificações. Rio de Janeiro, Brazil: ABES/PROSAB 4. cap. 3, pp. 73–152.

Haralick, R.M., Shapiro, L.G., 1992. Computer and Robot Vision, Addison-Wesley, New York City, USA.

Lee, I-C., Cheng, L., Li, R., 2010. Optimal parameter determination for mean-shift segmentation-based shoreline extraction using lidar data, aerial orthophotos, and satellite imagery. In: Proc. of the ASPRS 2010 Annual Conference, San Diego, CA, USA (on CD-ROM).

Schatzmann, A.P.M., Kreutz, C., Arantes, E.J., Passig, F.H., Carvalho, K.Q., 2009. Avaliação da possibilidade de uso da água de chuva no Campus Barigui da Universidade Tuiuti do Paraná. In: 25º Congresso Brasileiro de Engenharia Sanitária e Ambiental. ABES – Associação Brasileira de Engenharia Sanitária e Ambiental. Recife, Brazil.

Sithole, G., Vosselman, G., 2004. Experimental comparison of filter algorithms for bare-Earth extraction from airborne laser scanning point clouds. ISPRS Journal of Photogrammetry and Remote Sensing 59(1-2), 85-101.

Weidner, U. 1996. An Approach To Building Extraction From Digital Surface Models. International Archives of Photogrammetry and Remote Sensings XXXI(Part 3), 924-929.