Estimating Rooftop Capacity for PV: Are we asking the right question?

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Abstract

Precise estimation of solar energy potential on pitched roofs is crucial for modelling photovoltaic (PV) installation scenarios. However, there is no national database of building characteristics in the UK. This paper begins by reviewing and testing a range of existing techniques for identifying roof characteristics. These all attempt to estimate roof area with varying degrees of accuracy. Rather than attempting to achieve this, a method is developed which assesses each roof to discover whether it is suitable for PV installation. That is, its properties should allow the installation of at least a minimum size photovoltaic system.

This contribution provides a tool to assess PV potential on city-wide scales. It develops a pixel-based approach to estimation of solar energy potential over pitched roofs. This is achieved by a combination of publicly available building outline maps and LiDAR (Light Detection and Ranging) data. These are analysed by using a simple statistical technique within a Geographical Information Systems (GIS) environment.

The accuracy of the new method is known, following validation against a large housing database. The method is mathematically simple. It is suitable for estimating rooftop capacity of mixed housing type developments.

Implications of 3D rooftop characteristics for photovoltaic systems installation and yield

There is strong growth of PV in the built environment. Modern living space offers a range of challenges and opportunities for solar panel installation. The tilt and azimuth of a PV system have two influences on energy yield. First, there is an increase or decrease in annual energy yield depending on the suitability of the roof pitch and azimuth. Second, the daily or seasonal timing of peak energy generation is influenced. Existing housing stock does not always allow the use of optimal tilts and azimuths. Compromises in deployment are necessary. In order to understand this complexity, it is necessary to have knowledge of the roof characteristics of current buildings.

Research Methodology

There has been substantial previous research into computerised recognition of three-dimensional structural features. This area of research is challenging in terms of both data quality and the sheer size of LiDAR datasets. Additionally, 3D feature extraction is non-trivial. First, existing methods using both LiDAR and aerial photography as inputs are tested. The advantages and disadvantages of these techniques are reported, and the results presented in Table 1. These methods include model driven, peak detection, iterative voting, LiDAR edge detection, image edge detection, image recognition and ambient occlusion.

LiDAR obtains a grid of height values from an aircraft flying at constant altitude pulsing a laser to Earth and timing the returns. The number of returns per square metre determines the resolution of the data. LiDAR supplies detailed heights of objects (e.g. buildings and vegetation), as well as terrain surface. In the UK, LiDAR data is supplied by the Environment Agency [1]. Several resolutions are available for limited areas. 1m resolution was chosen as the best compromise between accuracy and availability. It covers approximately 70% of England. Roof characteristics may be extracted from this gridded height data. Aerial photography was obtained from GoogleEarth [2].

A new approach is then elaborated.

Two case studies are used to test the methods. The first is the Wollaton Park area of Nottingham. This was selected for the variety of architectural styles displayed by its houses. The second is a set of about 2000 housing association domestic installations in Nottingham. Locations, system sizes, and installers' tilts and azimuths of these systems have been gathered from a monitoring portal.

Method (see [5] for refs.)	Data	Result
1) Model driven	LiDAR 1m	To many model types in UK (> 50)
2) Peak detection	LiDAR 1m	Hard to distinguish peaks (noisy data)
3) Iterative voting: region-growing, RANSAC, Hough	LiDAR 1m	Require initial edge detection
4) Edge detection: Canny, high pass filter	LiDAR 1m	Fails due to noise and low resolution of data
5) Image detection: Gaussian, Sobel, Laplace	Aerial photos Google Earth	Only two planes of four-plane roofs distinguished. Need photos at different times of day.
6) Image supervision: supervised & unsupervised	Aerial photos Google Earth	Only two planes of four-plane roofs distinguished. Need photos at different times of day.
7) Ambient Occlusion (shading & rendering)	LiDAR 1m	Generates shading patterns at different times of day. Most promising of these methods but tendency to produce false shadows.

Table 1. Results of test of existing methods of rooftop PV estimation

Table 1 shows that there are many difficulties with existing rooftop methods. None of the above methods works well with the data resolution available in the UK (1m for the most part). The following sections present an alternative methodology to conventional rooftop PV models.

Method to discover whether roofs are suitable for minimum size PV installation

Instead of beginning by segmenting roofs into planes, this method takes the following question as its premise: "Is this roof suitable for PV?". The suitability checklist has three elements: (1) azimuth East through South to West; (2) space for at least a minimum size photovoltaic system ($8m^2$ of roof area for a 1kW system); (3) pitched roof tilt of between $15°$ and $60°$ (flat roofs are treated separately). This new approach comprises the subsequent steps which are displayed graphically in Figure 1. ArcGIS [3] software is used.

1. Extract building height points only from the LiDAR grid, using OS Mastermap Topography layer [4] as a "cookie cutter". That is, heights of all other objects e.g. trees, cars, bus shelters are removed (Figure 1, [1]).

2. The tilt and azimuth of each roof pixel is calculated using the Slope and Aspect functionality of ArcGIS software (Figure 1, [2]).

3. Calculate the mean of tilt for the whole roof. All major planes are assumed to have the same tilt and using the whole roof improves accuracy. Exclude all roofs with tilts not between $15°$ and $60°$. Those roofs with a tilt of less than $15°$ are too shallow for accurate azimuth estimations and are re-classified as "flat".

4. Calculate the mode of azimuth for all the pixels contained by each roof boundary.

5. At the outset, all houses are assumed to have simple two plane roofs but the area is visually checked using GoogleEarth and if more complex building forms are present, extra steps are implemented:

a. Two plane houses: taking due North as zero degrees, if the mode is greater than $270°$ and less than $90°$, swap by $180°$ to obtain the south-facing plane suitable for PV. Theoretically a two plane house should have two azimuth "modes" but by chance (and inaccuracies in LiDAR) one will prevail. Every non-flat building must have at least two opposite aspects.

b. Four plane houses: if the mode is greater than or equal to 90° and less than or equal to 180°, then add 90°. If the number of west-facing pixels is greater than the number of east-facing pixels, take the west-facing ones. These deliver a higher solar yield and it is unlikely both roof planes will have PV installed due to the cost.

c. Three plane houses: as for four. However, one aspect will be missing. If no actual pixel values are within 10° of the swapped mode, the swap is abandoned.

d. More than four major planes – this research does not attempt to include complex roof formats because these are considered unsuitable for PV.

6. Pick out roofs in the southern half of the compass only: East through South to West.

7. Select pixels within half a standard deviation of the mode (Figure 1, [3]).

8. Perform a Rook's Case connectivity check to eliminate roof areas connected diagonally (by the corners) because solar panels cannot be installed in this situation (Figure 1, [5]).

9. Apply a minimum 10 pixel filter to the selected pixels to remove small areas (Figure 1, [6]).

10. Carry out a boundary clean to remove dangling pixels etc

11. Size of the roof patches may be computed. However, all patches selected now meet the minimum requirements for PV, which is the aim of this approach.

The decision was taken to work with the azimuth as the most influential characteristic for photovoltaic yield. Also, experience proved the azimuth to be subject to less minor variations than the tilt, hence it was easier to aggregate pixels around a statistical value. An experiment on ten houses where the azimuth could be measured revealed the mode to be the most successful statistic for aggregation. (As opposed to mean, maximum etc). There is less skewing effect from errors.

The following statistical methods were tested for selecting azimuth pixels around the mode:

• Equal interval +/- 45 degrees.

• Jenks Natural Breaks

• Half standard deviation of mode. This collects one third of roof data (68% std/2).

• One third standard deviation of mode. This collects about a quarter of roof data (68% std/3 = 23%.

• One quarter standard deviation of mode. This collects about one sixth of roof data (68% std/4 = 17%).
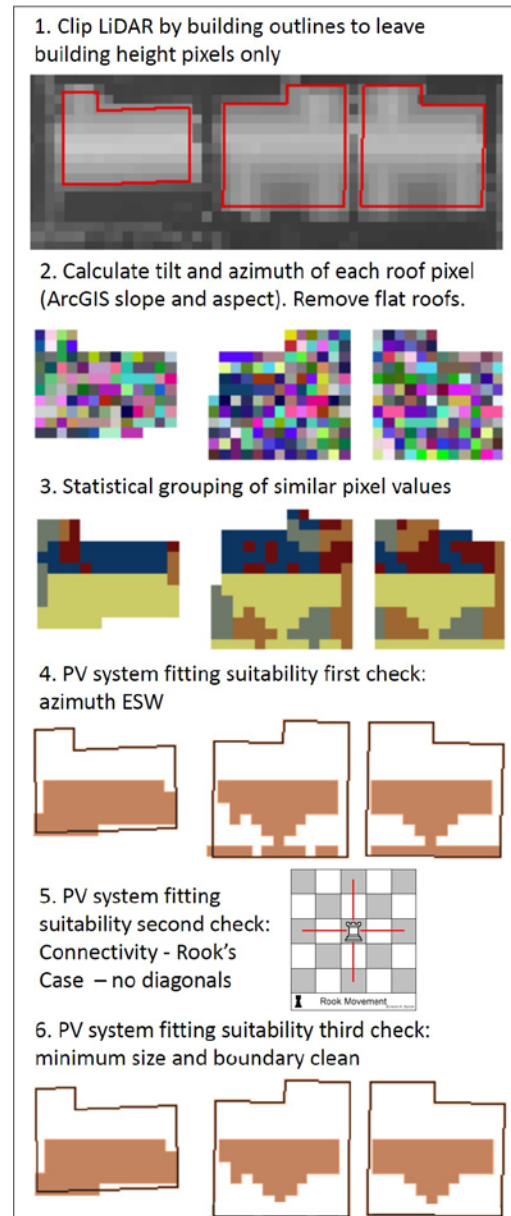

Figure 1. Method to discover whether Roofs are suitable for minimum size PV installation

These five techniques were tried on a database of housing association homes with PV installed. 886 of the homes are covered by LiDAR flights, making them usable as test cases. System size of each installation is known, so solar panel area may be calculated (1 kW = 8 m^2). The

horizontal roof patch area selected as suitable for PV in each case was corrected to tilted plane area with the cosine rule. It was found that the half standard deviation method delivered the most accurate results. It successfully identified roofs as suitable for PV installation for 97.5% of the housing association homes which are already fitted with systems. The other four techniques failed about twice as frequently. Manual comparison of the more complex houses in the Wollaton Park case study with aerial photography also found the half standard deviation method to be preferable.

This method is compatible with the available LiDAR resolution and is achievable using a standard desktop PC. No specialist software is required, other than GIS. The process is mathematically simple. Automation is possible, but not essential. A detailed validation is described in the next section.

Validation of new method

The new method is validated against data from a selection of approximately 2000 housing association PV systems currently installed in Nottingham, UK. 886 of the homes are covered by LiDAR, so an extensive validation is possible.

60% of the LiDAR estimated tilts were found to be within 5° of the figure in the housing association database. 88% of the LiDAR estimated tilts were within 10° of the installer's estimates. Given that homogeneous houses vary by 3° [5], these are acceptable results.

33% of the LiDAR estimated azimuths were found to be within 5° of the housing association figure. 66% of the LiDAR estimated azimuths were within 15° of the installer's estimates. Again, these figures are considered to be satisfactory.

Roofs suitable for PV installation were correctly identified in 97.5% of cases.

Conclusion

The tool developed here can be a powerful resource for investigating the deployment of rooftop PV. It can assist network operators in evaluating how much electricity the UK's domestic solar panels can produce (with worst-case/minimum system sizes) and improve the efficiency of the electricity network.

It does not focus on obtaining precise values of tilt, azimuth and roof area but simply asks, "is this roof suitable for PV installation?". Thus, the minimum PV capacity for any city region may be estimated and hence minimum solar yield. The maximum sized systems may not be installed on houses in any event, due to cost, aesthetics or fairness between rented properties.

The new method works on the basis of selecting pixels within half a standard deviation of the azimuth mode. The mode is the value at which the peak of the distribution curve occurs. It is a flexible approach to handling non-ideal data, where standard peak finding algorithms cannot cope with the noise. The end result is a map of roofs suitable for PV system installation; size at least 1kW, known tilt and azimuth. These results can be aggregated by region to calculate the lower boundary yield per area.

This technique has been extensively validated against an installation database.

References

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[5] Palmer D, Cole I, Betts T, Gottschalg R. Assessment of potential for photovoltaic roof installations by extraction of roof tilt from light detection and ranging data and aggregation to census geography. IET Renew Power Gener 2016;10:467–73.