Using High-Resolution Remote Sensing Images to Detect Suitable Rooftops for Solar PV Installation in Urban Areas in Da Nang City

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ABSTRACT

Global warming due to climate change has become an issue of great concern worldwide, especially for countries suffering from direct impacts and facing great risks of damage from climate change like Vietnam. Reducing and phasing out fossil fuels together with promoting, investing in and developing alternative green energy sources such as solar energy are important not only for Vietnam but also for the global sustainable development. . In a context where the energy industry is one of the largest GHG emitters in Vietnam, the Vietnam Government is focusing, with great efforts, on how to promote the use of solar energy on building rooftops. This paper presents the first results of the World Bank's project "Assessment of Technical Rooftop Solar PV Potential in Vietnam" carried out by Effigis Geo-Solutions Inc., Canada, and CEFD, Hanoi University of Science. In this project, a stereo pair of WorldView-3 images of the central urban area of Da Nang City were geometrically processed, pan-sharpened and then used for rooftop and shadow detection, as well as rooftop height, slope and aspect computing using, among others, machine learning methods. Terrain data will be used for validation of image processing results. Based on a suit of technical criteria required for PV installation, some 500 rooftops were selected from 646,958 ones in total by using image interpretation techniques. These 500 suitable rooftops then were used in field survey for validation purposes.

Keywords: technical rooftop solar PV potential, solar energy, remote sensing, WorldView-3, machine learning

I. INTRODUCTION

Vietnam is a developing country where the energy industry sector relies mainly on fossil fuels. By 2007, fossil fuels accounted for 92% of the total commercial energies in Vietnam, approx. 50% of which was coal, 33.4% was oil and 12% gas [1]. By 2025, the energy demands are projected to exceed the energy supply of the country if new alternative energy sources are not considered. Therefore, the promotion of renewable energy, including solar energy, becomes more and more necessary and attracts more concerns from the public. As possessing high solar energy potential with a total sunshine duration of 2500 hours/year and a total solar radiation per year of 230 – 250 kcal/cm^2[2], Vietnam therefore is assessed as a promising and ideal country for introducing, promoting and applying state-of-art green energy technologies, including rooftop solar PV.

Currently, two approaches are largely used for assessing rooftop suitability for PV implementation [3], [4]: (1) visual interpretation of aerial photography to identify and evaluate buildings on an individual basis to determine the total suitable area; and (2) automated GIS processing based on 3D models from LiDAR data. The first approach is costly, time-consuming and difficult to replicate on a large scale. The second one is limited by the high acquisition costs of LiDAR data. Trong nghiên cứu này, tác giả sẽ đưa ra một hướng tiếp cận mới, sử dụng và giải đoán ảnh WorldView-3, bộ ảnh vệ tinh độ phân giải siêu cao, tiết kiệm được thời gian và không mất nhiều chi phí.

In this project, Da Nang city was selected as the study area for its rapid urbanization, many green-development-oriented projects being implemented, and its potential urban areas and industrial zones for rooftop solar PV installation. The rooftop solar PV potential assessment in mega-cities requires the identification and characterization of rooftops in order to assess their surface area and to decide on their suitability in terms of slope, orientation, the presence of obstructions, shadings, etc. Among other satellite sensors, WorldView-3 currently offers the highest spatial resolution of 0.3 m x 0.3 m. At this resolution, rooftops appear clearly along with many of their characteristics, as well as objects and boundary elements separating them. Furthermore, the use of WorldView-3 stereo pairs allows calculating a digital height model (DHM) and retrieving the slopes of rooftops that are essential for several steps in the approach.

The research aims to detect, characterize and assess the solar PV potential of all HCMC rooftops and to apply ‘good practices’ criteria related to PV system implementation to rank their suitability. The 500 rooftops selected from 646,958 ones in total were used in field survey for validation purposes and upcoming PV implementation.

II. APPROACH AND DATA PROCESSING METHODS

The methodology was based on a combination of remote sensing, GIS and machine learning techniques to extract, from WorldView-3 stereoscopic pairs, rooftop footprints, along with their height, unobstructed surface area, slope, aspect and ratio of shading. This information, combined with data from the global solar atlas, was used to compute solar radiation received by each rooftop.

2.1 Required technical information

For the assessment of rooftop solar PV potential, a set of initial technical information needs to be addressed and derived from the satellite images as follows:

Rooftop footprint: to identify and to separate rooftops from other objects (roads, bare soil, vegetation, water, etc.) within the area of study.

Building height: the height of buildings helps to eliminate false alarms (from ground-level surfaces) and helps to determine, for each rooftop, the areas shaded by the surrounding buildings.

Ratio of shaded surface area: computed by integrating the rooftop shaded area according to the evolution of the sun's position during daytime hours and the days of the year. This integration takes into account the hourly and daily variations of the received solar radiation by the rooftop.

Roof type: this factor affects the amount of solar irradiation that a roof can receive according to its geometry (slope and orientation) and thus defines its suitability for solar PV installation. Rooftop types can be classified as flat (one-sided), two-sided, four-sided, circular, curved, or complex (multi-sided).

Rooftop slope and aspect: these factors affect the amount of solar irradiation that a roof can receive from the sun since the global horizontal solar irradiation on a tilted surface (GTI) depends on the extent of tilt and angle of orientation with respect to the sun. The rooftop slope (when not tilted) is derived from the DHM; the aspect is calculated using a GIS function.

Obstructions: the percentage of obstructions is one of the factors considered to decide the suitability of rooftop solar PV installation as well as to affect the total rooftop surface area.

Rooftop suitable surface area: it is the most important factor to decide how much solar irradiation a roof can receive. It depends on the footprint, the shape (due to a maintenance buffer), the proportion of obstructions and of shaded area.

Land use type: this factor identifies on which type of land use rooftops are located (public / private house / industrial building / cultural building / rural / urban land, etc.). Land use type, coupled with roof surface area, will determine whether it is possible to install rooftop solar PV systems or not. Besides, this factor may be determining as to the feasibility of installing rooftop solar PV systems because of the administrative roles (national defense building, post office, hospital, school, etc.) and authorization characteristics (restricted area, public area, governmental properties, etc.) of each building.

2.2 Input data for information extraction

A stereoscopic pair of WorldView-3 images

The imagery consisting of 2 pieces with a spatial resolution of 0.3m acquired on12/08/2017 was used to cover the entire area of interest (AOI) in Da Nang city with a total area of 175 km^2 (Figure 1). Standard pre-processing of the WorldView-3 images, carried out before their use for further calculation and analysis, included: orthorectification, pansharpening, rescaling from 11-bits to 8-bits (0-255), enhancement and image compression (from GeoTIFF to jpeg2000).

Figure 1 *WorldView-3 image for the AOI of Da Nang City*

Digital Surface Model (DSM)

A Digital Surface Model (DSM) was extracted from the WorldView-3 stereoscopic image pairs using the following operations: importing the stereoscopic pairs into the image processing software, aerotriangulation with tie points, automatic correlation and conversion of Triangulated Irregular Network (TIN1) format to raster. The DSM with 1 m resolution was used to compute the Digital Height Model (DHM) and detect shadows

Digital Terrain Model (DTM)

Digital Terrain Model (DTM) at 10 m resolution, provided by the Center for Environmental Fluid Dynamics, VNU-HUS, Hanoi, Vietnam (CEFD), represents the information of the ground level

Digital Height Model (DHM)

Digital Height Model (DHM) was computed as the difference between the DSM and the DTM above. The DHM was used to calculate building heights.

2.3 The processing of HR images and the derived technical information

2.3.1 Methods of rooftop and shadow detection

Automatic detection of buildings and rooftops from high-resolution (HR) satellite images has been a topic of major interest for various applications, especially in urban areas. Types of image data used for building detection are diverse such as: multispectral images, DSM, DEM, SAR, LiDAR, etc. The existing methods can be categorized into two groups: (1) Building detection using 3D image data sets; and (2) Building detection through monocular remote sensing images [5]. Obtaining rooftops from HR satellite images by segmentation is initially required in order to subsequently extract specific rooftop information including area, slope, aspect, type and function of building for the purpose of rooftop solar PV installation. There are many methods for urban object segmentation from high-resolution images among which supervised classification system based on Support Vector Machines (SVM) can be used (Inglada J., 2007). This algorithm is used in our object-oriented (O-O) classification which consists of the following steps:

- Multi-level segmentation;
- Elimination of small and elongated objects;
- Detection of rooftops (classification and fusion) according to spectral signature, shape, and DHM.

After the image segmentation step, a manual check was required to guarantee some information as follows:

- sub-parts of rooftops were fused and aggregated (when rooftop color is not homogeneous);
- Elimination of false alarms (i.e. sides of buildings when acquisition angle is high; roads when DHM is not available due to clouds and their shadows, etc.);
- Addition of the undetected rooftops (hidden by clouds or their shadows);
- Completion of partial rooftops (hidden by trees).

Shadows of the building occurring in regions are not illuminated by the sunlight due to obstruction by others buildings. There are different methods of shadow detection. In our case, shading was calculated using a GIS function based on the DSM and the sun's position for each month and varying times of day between sunrise and sunset.

2.3.2 Methods of extraction of rooftop technical specifications

The application of deep learning to information extraction from very high-resolution satellite imagery is a relatively recent subject. The relevance of this application was demonstrated by, among others, Dahmane et al., 2016 [6] and Penatti et al., 2015 [7]. This approach was used to classify the types of rooftops (flat vs. tilted, the number of sides and the level of obstruction). Upon visual assessment of the WorldView-3 images, nine rooftop types were identified: flat without obstructions; flat with 0 to 10 % obstructions; flat with 10 to 30 % obstructions; flat with ≥ 30% obstructions; two-sided; four-sided; complex; curved (semi-cylindrical); and circular (conical). (Figure 2):

Flat without obstructions | Flat with 0 - 10 % obstructions | Flat with 10 - 30 % obstructions | Flat with > 30 % obstructions

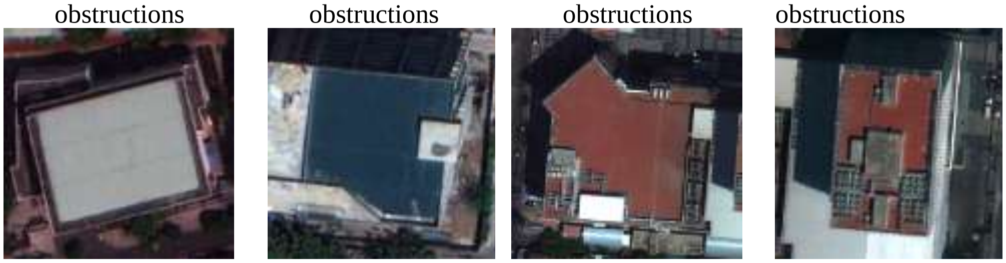
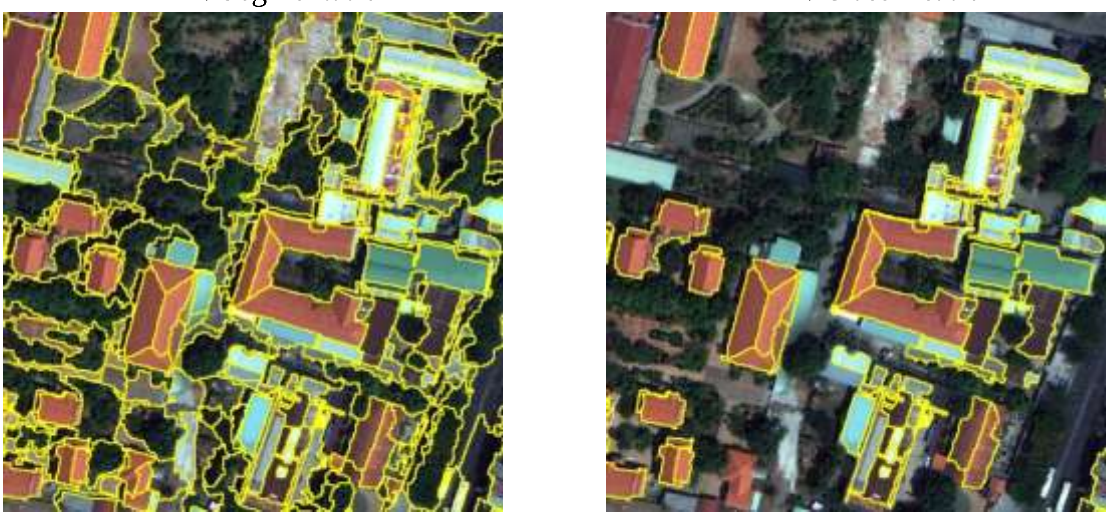


Figure 2 *Rooftop type extracted by the deep learning algorithm*

III. RESULTS

3.1 Rooftop and shadow detection from HR WorldView-3 Images

The object-oriented classification chain included segmentation, classification, fusion and quality check. The application of this processing chain to the WorldView-3 images covering the entire study area led to the detection of 646,958 rooftops. (Figure 3)



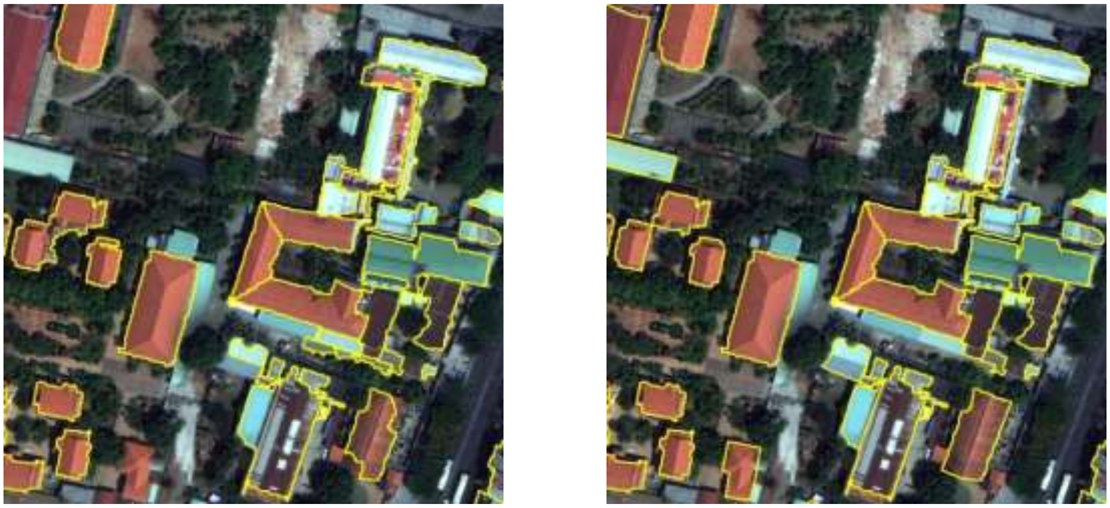


Figure 3 *Example of results of rooftop detection steps using an O-O classification approach*

Figure 4 *Rooftop in the AOI in Da Nang city were detected by the O-O method*

Figure 5 shows examples of the good correspondence between rooftop shape (on the WorldView-3 image) and the DHM. Slope of roof is defined as below:

$$\mathrm{Atan}[(H_{max} - H_{min})/(\mathrm{Width}/2)]$$

Small variations in rooftop height indicate a flat rooftop.

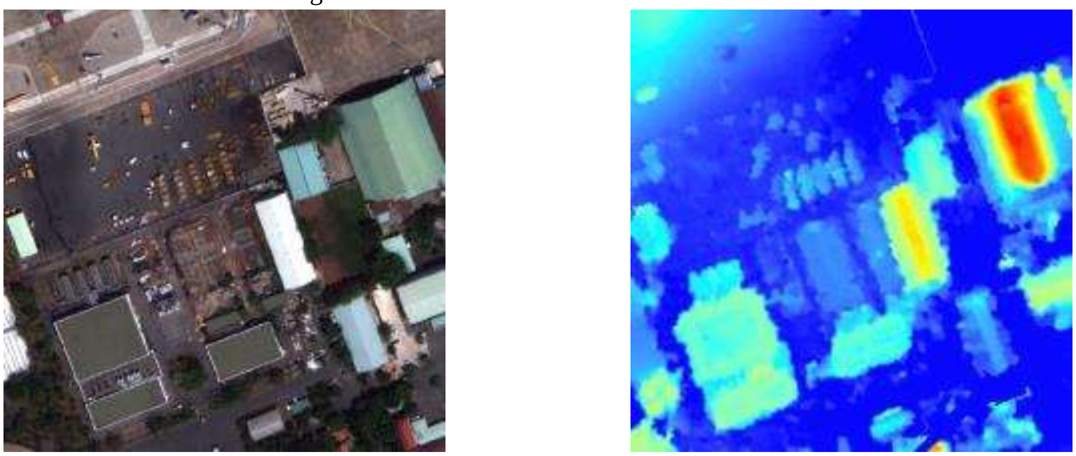


Figure 5 *Correspondence between rooftop shape and DHM used for slope estimation*

Figure 6 shows an example of building-generated shading simulated for different time of the day and on a specific month of a year and using DSM to detect shadow. Building shading was recorded largest for the taller buildings at the times close to sunset and sunrise.

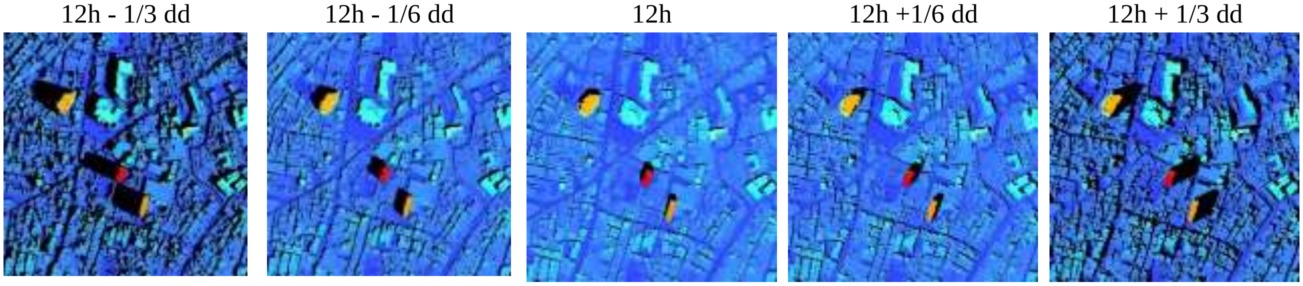


Figure 6 *Evolution of building-related shading for certain times of day*

The surface area of each detected rooftop was reduced by a 1-m buffer ($A_{reduc\text{-}buff}$) and corrected for obstructions and shading. The rooftop surface area that is suitable for PV system installation ($A_{suitable}$) is defined as follows:

$$A_{suitable} = A_{reduc\text{-}buff} \,.\, (1\text{- ratio of obstructed area}) \,.\, (1 \text{ - ratio of shaded area})$$

Some statistics are shown in Table 1:

Table 1 *Statistics on the areas of rooftops detected from WorldView-3*

Total surface area	**174,690,000 m^2 (175 km^2)**
Total area of rooftops identified	28,613,785 m^2
Total area of suitable rooftops	9,145,406 m^2
Ratio btw. Suitable roof area and total roof area	32%
Non-obstruction rooftops	3,967,929 m^2
Rooftops with 0-10% obstruction	818,634 m^2
Rooftops with 10-30% obstruction	376,657 m^2
Rooftops with >30% obstruction	7,733 m^2
2-sided rooftops	3,681,278 m^2
4-sided rooftops	88,515 m^2
Others (curve, complex…)	204,662 m^2

3.2 Technical rooftop solar PV potential assessment

Global solar irradiation (in kWh) received by a rooftop during a given year is simply the product of the global solar radiation extracted from the Global Solar Atlas (in kWh/m^2 per year) by the suitable area of the rooftop ($A_{suitable}$ (m^2)). The application of this rule is simple for global horizontal irradiation (GHI) and global irradiation received by latitude inclined surfaces, regardless of rooftop type. For flat rooftops, global tilted irradiation is equal to global horizontal irradiation and therefore simple to calculate. However, the assessment of the global tilted irradiation received by tilted rooftops needs to take into account the rooftop type as well as slope and aspect, in addition to suitable surface area Asuit and the Global Tilted Irradiation value extracted from the Global Solar Atlas for the corresponding slope and azimuth.

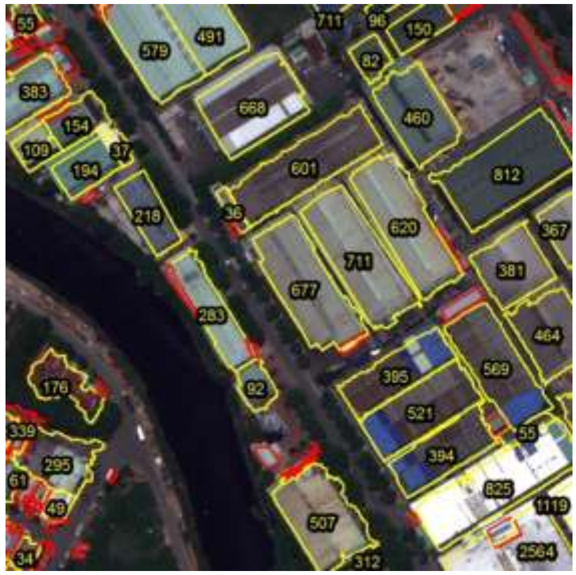


Figure 7 *Examples of total yearly PV energy produced by HCMC rooftops in MWh*

Some statistics are shown in Table 2

Table 2 *PV Energy estimated for different types of rooftops*

Global horizontal irradiation (GHI)	**3,189,917 MWh**
Optimal Global tilted irradiation (GTI – optimal)	**3,231,986 MWh**
Annual global irradiation on a tilted-surface (rooftop slope)	**3,088,135 MWh**
By rooftop types	
Non-obstruction rooftops	1,384,013 MWh
Rooftops with 0-10% obstruction	285,539 MWh
Rooftops with 10-30% obstruction	131,377 MWh
Rooftops with >30% obstruction	2,697 MWh
2-sided rooftops	1,284,029 MWh
4-sided rooftops	30,874 MWh
Others (curve, complex…)	71,386 MWh

IV. DISCUSSION

This paper presents a new methodology for assessing technical rooftop solar PV potential, based on conventional (photogrammetry, object-oriented classification) and advanced (deep learning) image processing techniques, applied to very high-resolution satellite imagery. The approach yielded very satisfying results, especially given the cost of the data and the processing time.

The results show that Da Nang City has a huge potential for producing PV electric energy from its rooftops. The information that has been extracted using this methodology can be used by Da Nang decision makers to plan and develop the renewable solar energy sector towards the green development orientation of the city.

Beside those big advantages, very high-resolution satellite imagery (VHRSI) like WorldView-3 is however still costly to be applied more commonly and widely, especially in the countries which are still developing or under-developed. Beside, in case of the rapidly-urbanized city as Da Nang, the frequent update of images is also important and should be taken into account since the land use change in this area is very fast (in some areas, buildings are under the city clearance zone)

ACKNOWLEDGEMENT

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