SIMULATING SOLAR RADIATION UNDER CANOPY USING POINT CLOUDS AND AN HEMISPHERICAL PHOTOGRAPHY SIMULATOR

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Abstract

Solar radiation illuminating the canopy and reaching lower strata of vegetation is an important ecological factor that can enhance biodiversity and contribute to species composition in habitats. It is also part of the many factors that make a natural environment a positive contribution to the health and wellbeing of people interacting with it. Aerial survey methods using drones can now provide digital twins with a very high level of detail. In this work, we developed a software, lasPhotoCamSIM, for simulating hemispherical imagery using dense point clouds as input data. The simulated hemispherical images are used to map the diffuse solar radiation reaching the average height of the human eye from the ground. For the sample design, a regular grid with nodes at 0.5 m ground sampling distance and 1.5 m height from the terrain was used. The study area is a historical garden, Villa Revedin Bolasco. It was surveyed via a drone flight with three sensors, two LiDAR sensors (Riegl VUX-120 and Riegl miniVUX-3UAV) and a camera. The camera provided overlapping imagery that was used to create a third point cloud using photogrammetry. The three point clouds were used as input data to lasPhotoCamSIM together with coordinates of the nodes of the grid, resulting in ~330,000 virtual hemispherical images. Gap fraction and estimated solar diffuse radiation was calculated from each hemispheric image, and it was then converted back to a regular raster map.

Keywords: LiDAR, health, photogrammetry, point clouds, hemispherical imagery, digital twins, virtual/extended reality, human well-being.

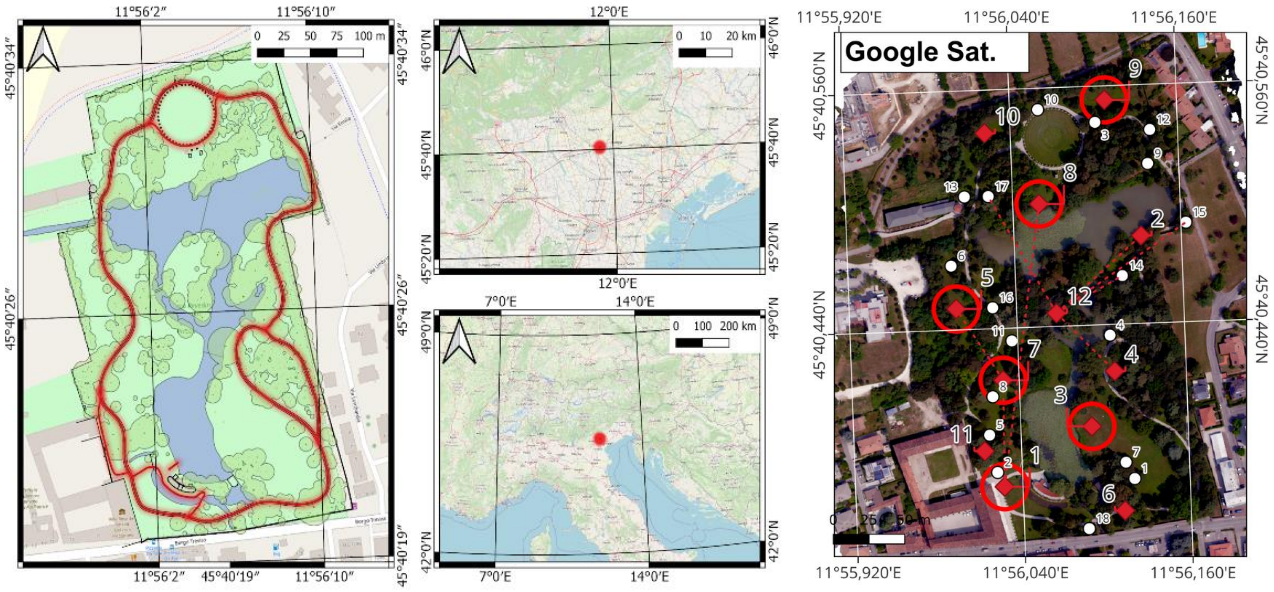
1. INTRODUCTION

Sun radiation penetrating under the canopy is an important ecological factor that can enhance biodiversity and contribute to diverse habitats (Smith et al. 2008). It is also part of the many factors that make a natural environment a positive contribution to the health and well-being of those who interact with it and indirectly supports one of the United Nations Sustainable Development Goals (UN-SDG). Sun radiation can be estimated from the gap fraction from the sky view at a certain point. Gap fraction can be estimated in several ways from below or above the canopy and using different approaches such as field observation, remote sensing and GIS software (Pereira et. al 2002) or airborne LiDAR (Korhonen et al. 2011). Hemispherical photography is widely applied in situ to estimate the illumination and gap fraction, and many software are available for hemispherical image processing (Promis et al. 2011). However, it is expensive to physically survey large vegetated areas, and in a scenario with very dark understorey due to thick canopy cover, this technique suffers from exposure issues (Glatthorn and Beckschäfer 2014). Nowadays, Aerial LiDAR acquisition takes advantage of drones, so aerial surveys can now provide digital twins quickly and with a very high level of detail. The digital twins can in turn be used for further analysis of the environment with geometrically accurate and reliable information. In this work, a software was developed, lasPhotoCamSIM, for simulating hemispherical imagery using dense point clouds. The simulated images are used to map the estimated diffuse solar radiation and gap fraction over a virtual surface at human eye-level in the study area.

2. MATERIALS AND METHODS

2.1. STUDY AREA

The study area is the historical garden of the Villa Revedin Bolasco (VRB) located in the city of Castelfranco Veneto (province of Treviso), Northeast Italy. The area was historically owned by noble families, Tempesta, Morosini and Corner. In the middle 19th century, Francesco Revedin built his residence and the English garden. The garden reveals a complex topography of, views of the lake, bridges, meadows, man-made hillocks, and depressions such as the equestrian arena. Today, the historical garden extends over an area of 7.63 hectares (Fig. 1) and counts over 1,000 trees.



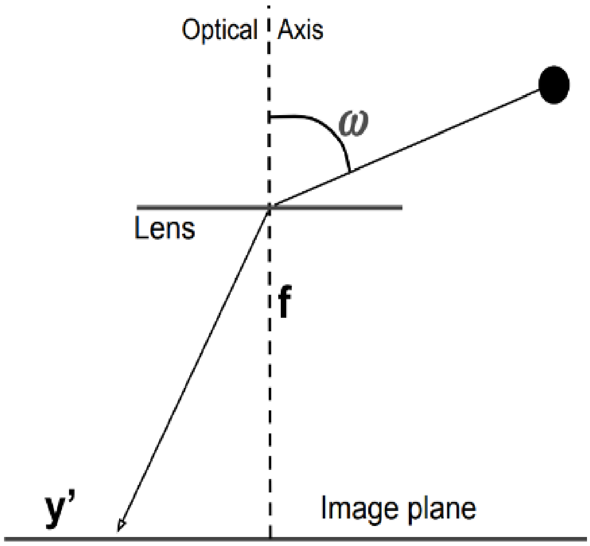
. **Fig. 1.** Study area, the garden of Villa Revedin Bolasco.
Geographic coordinates refer to the WGS84 datum. The right-most image represents ground control points.

2.2. SURVEYS

Three UAV flights were carried out on July 22nd, 2021 inside the garden. The UAV carried three sensors: Riegl VUX-120 and Riegl miniVUX-3UAV and Sony ILCE-7RM3 camera. Riegl VUX-120 and Riegl miniVUX-3UAV are airborne laser scanners used for topography, forestry, and agriculture application. Riegl VUX-120 has a maximum measurement rate of 1,500,000 measurements per second, whereas Riegl miniVUX-3UAV offers a maximum measurement rate of 200,000 measurements per second. Sony ILCE-7RM3 RGB camera has 43,6 megapixel and the CMOS Exmor R full-frame 35 mm sensor. Several targets were used as Ground Control Points (GCPs) whose coordinates were acquired with a GNSS receiver in RTK mode (Fig. 1). The overall accuracy (RMSE) is 2.20 cm and 2.73 cm horizontally and vertically respectively. The GPCs are necessary for the photogrammetric process and for checking the final accuracy of the three models. The photogrammetric point cloud has been elaborated with Agisoft Metashape©. Finally, we have estimated the average density of the three point clouds, which is 20,000 points per square metre for the VUX-120 sensor, 2,000 points per square meter for the miniVUX-3UAV, and 10,000 points per square metre for the photogrammetric cloud.

2.3. LASPhotoCamSIM

The LASPhotoCamSIM is an open-source software developed in C++ using the LASLib library (Isenberg, 2022). It is available and shared through GitHub (Pirotti, 2022). The tool tests rays that are traced between the camera centre and points (Fig. 2). These light rays are projected on a raster image whose resolution can be defined by the user.



. **Fig. 2.** Resulting images from processing point clouds with LASPhotoCamSIM

It projects the points from the point cloud to spherical coordinates with respect to a hemispherical dome around the camera using 5 lens projection models: equiareal (1), equidistant (2), stereographic (3), orthographic (4) and rectilinear (standard perspective) (5). estimating how much obstruction they create.

equiareal/equisolid: $y'(\omega) = f \cdot \sin(\omega / 2)$ (1)

equidistant: $y'(\omega) = f \cdot \omega$ (2)

stereographic: $y'(\omega) = f \cdot tg(\omega / 2)$ (3)

orthographic: $y'(\omega) = f \cdot \sin(\omega)$ (4)

perspective: $y'(\omega) = f \cdot tg(\omega)$ (5)

The hemispherical images are produced simulating the zenith direction of a camera held on a virtual tripod placed inside the garden resulting in pixels representing the degree of obstruction to light depending on how many points fall inside the discrete cell (Fig. 3). The historical garden surveyed here, however, does not have a flat topography, but a complex terrain, so the virtual 3D position of the camera has been defined using a digital terrain model (DTM). The DTM has been created by processing the highest resolution point cloud with LAStools© software. The camera locations have been extracted over a grid with nodes at 0.5 m x 0.5 m distance in north-south and east-west directions respectively. The height of the virtual tripod, which holds the camera, was defined at 1.5 meters, and the radius of analysis to 50 meters around each position. This created about ~330,000 hemispherical images.

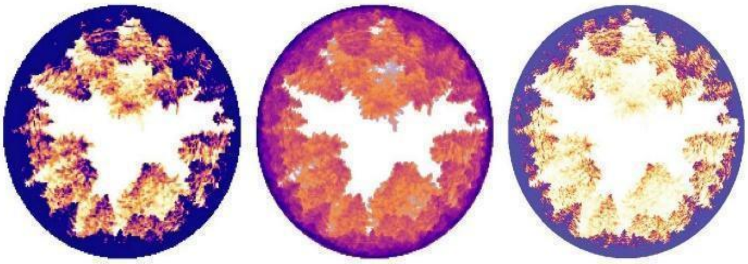


Fig. 3. Example of images from processing point clouds with LASPhotoCamSIM using different parameters. The colour scale is proportional to the obstruction degree of solar radiation.

3. RESULTS

Three gap fraction maps have been produced over the square grid (Fig. 4). Riegl mini VUX-120 and Riegl mini VUX-3UAV look similar, except for the southern part as the former had a smaller area covered by the flight. The red colour indicates the areas with high density in canopy cover whereas the gaps are blue. Small differences are located at the boundaries of vegetated areas. The photogrammetric gap fraction map slightly underestimates the canopy cover, e.g., in the southeast of the garden.

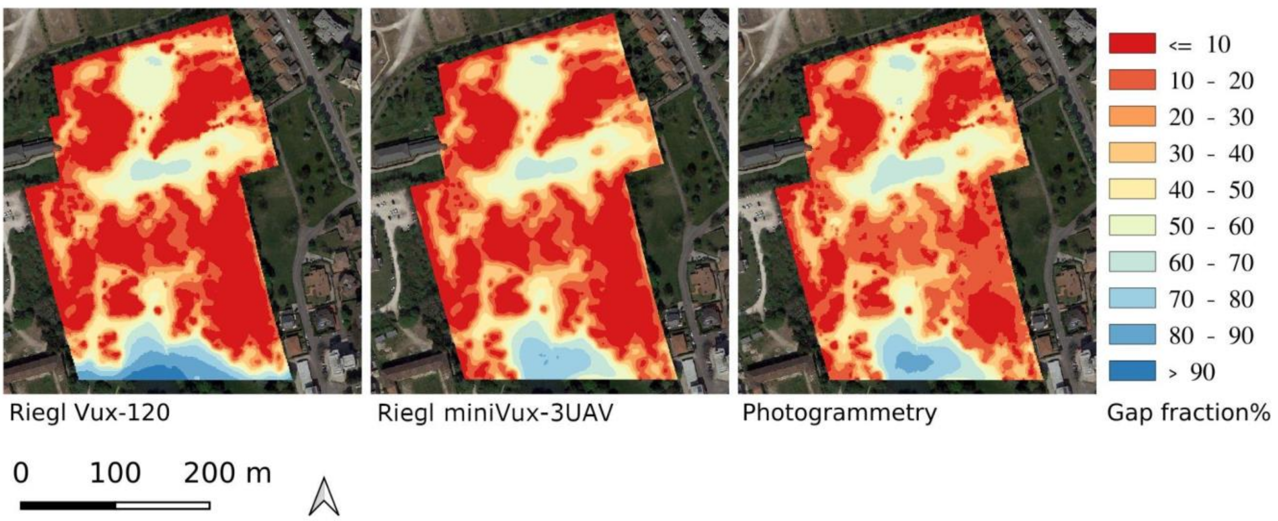


Fig. 4. Gap fraction map of the three points cloud. Red colour indicates dense vegetation. Blue colour indicates sparse vegetation and the lake.

Statistical raster analysis highlights the Rigel VUX-120 produces higher canopy cover, whereas the ranges of values obtained by Rigel VUX-3UAV and photogrammetry are similar. Moreover, the differences are in the minimum and maximum values as reported in Table 1.

Table 1. Result of the statistical analysis over the three maps of gap fraction.

Statistics	Riegl VUX-120	Riegl miniVUX-3UAV	Photogrammetry
Max	95.4	80.2	82.3
Mean	24.3	24.0	27.3
Min	0.1	0.3	1.6
Range	95.3	79.9	80.7
Std_dev	23.8	20.6	20.1

4. CONCLUSION

The goal of this work is to compare three gap fraction maps to estimate solar radiation using three-point clouds. We simulated hemispherical photos to estimate diffuse radiation from all directions of the sky-view dome. High-density LiDAR sensor Riegl VUX-120 maps the canopy cover to higher values than the other two maps with a difference of 15%. The performance in the vegetated areas seems similar. Photogrammetry and Riegl miniVUX-3UAV LiDAR have a difference in densely vegetated areas. Riegl miniVUX-3UAV LiDAR has higher estimation of the gaps and the crown of the vegetation. In contrast, a photogrammetric point cloud, produced with the typical nadiral orientation of the cameras, seems to underestimate the gap canopy cover and thus the solar radiance that is perceived by the person at a certain position. Further analysis will define the spatial distribution of open vs closed areas. Future developments will use virtual modifications of the digital twins, i.e., the point clouds, to map changes in solar radiation spatial distribution of the historical garden.

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