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Primary results of using hemispherical photography for advanced GPS mission planning

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Abstract

This paper presents a preliminary results of using hemispherical digital photography obtained from fish-eye lens for advanced GPS mission planning. Nowadays, reach GPS constellation ensure availability of 3 dimensional position, anytime, anywhere over the world, except, where the obstructions prevent signal receiving occur. At urban area, so called "urban canyon" and under some tree canopy a careful and taking into account the shape and type of terrain obstacles mission planning is still essential. Currently available mission planning applications allows to create obstruction diagram just manually, by determining each obstruction point by point (azimuth and elevation) which is inefficient. Other, described in the literature solution requires 3D digital building and other obstructions models, that are not yet widely available besides the large urban agglomerations. A vertical fish-eye image seems to be a great tool for direct determining of a site satellite window diagram giving complete view of site. This method is also easy and cost and time efficient. In the work, accuracy of obstacles shape determination, compared with tacheometry as a reference was examined. Afterwards, the efficiency of the proposed solution was tested at both urban and wooden area.

Keywords: GPS mission planning; Hemispherical photography; Terrain obstruction; Fish-eye lens.

1. Introduction

In the early years of the GPS system, when the constellation was not fully deployed, there was a need of sedulous and strategic GPS mission planning. In geodetic surveying it is especially important to ensure the simultaneous satellite visibility from at least a pair of stations [1]. For this purpose an approximate coordinates of measurement site, planned observation time and satellite coordinates determined from the almanac data are necessary. With that data, time and observation site related diagrams of satellite visibility and DOPs as well as sky-plots could be easily generated. Nowadays, full deployment of GPS constellation, consists of 31 satellites [2], ensure availability of 3 dimensional position anytime, anywhere over the world. That is why, for ordinary surveying tasks, in open-sky environment, the planning of time of GPS observations seems to be no longer so important. However, obstructions like high buildings, bridges or some tree can prevent GPS satellite signal reception. The blockage has negative influence on solving the ambiguity of phase measurements by limits satellite availability. This causes significant decreases of probability and reliability of coordinates determination [3–5]. Thai is why, in urban area, so called "urban canyon" and under some tree canopy a careful and taking into account the shape and type of terrain obstacles mission planning is still essential.

The location related to the measurement point and the shape of terrain obstructions can be defined by pair of angles: azimuth and elevation. In the literature several methods of that angle determination are mentioned from the earliest like using engineer's theodolite [6] or so called floating lines [7] to hemispherical (analog firstly and digital now) photography and using digital terrain and 3D buildings models [8–9]. The most advanced methods of mission planning are those based on 3D digital models. The main limitation of those methods is however, the lack of 3D terrain models besides the large urban agglomerations. Using of this method additionally requires *a priori* determination of measurement point coordinates with relatively high accuracy. On the other hand, ccurrently available and widely used mission planning applications allows one to create obstruction diagram just manually, by determining each obstruction, point by point, which is inaccurate and inefficient. In this paper some automatic, using cheap and easy to gain hemispherical photography method is presented.

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Hemispherical photography, despite its large amount of distortions, is widely and successfully used in different domains such as forestry [10], the study of plant canopies [11] and meteorology [12]. For the purpose of a site satellite window diagram direct determining, a vertical fish-eye image seems to be a great tool. Hemispherical image offers the advantage of providing spatially resolved information about all the obstacles above the GPS measurement point. What is more, for the involved task, no distances to measured objects or heights of them are needed. What should be measured is just azimuth and elevation which can be easily read of the image.

Proposed process of hemispherical based mission planning methods consists of steps as fallows. In the first step hemispherical, vertically orientated and centred over the GPS measurement point, digital photography should be done. For this purpose fish-eye lens camera and tripod with leveling head is used. The next step is to image segmentation and determining which segment refers to the obstructions, and which segment refers to *open sky*. The third step involves satellite coordinates in topocentric coordinates system calculation. And the finally, based on the obstruction model and the designated coordinates of satellites, the time-related, number of satellites and DOP values should be designated.

2. Fish-eye image geometry

The typical fish-eye lens construction consists of the multiple optical components, characterized by a 180-degree field angle (Fig. 1).

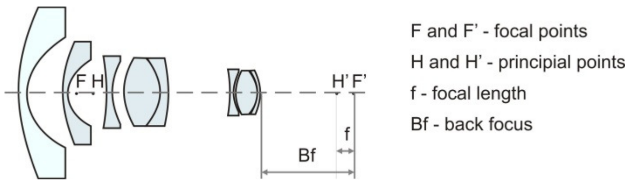

Fig. 1. Typical fish-eye lens construction

As a result of hemispherical projection, realized by fish-eye type lens, a circular, fully inscribed inside the frame image, surrounded by blackened area is obtained. The hemispherical projection, realized by fish-eye lens, based on the principle that the distance between an image point and the principle point is linearly dependent on the angle of incidence of the ray from the corresponding object point [13] (Fig. 2). The fish-eye lens utilize thus an equation $\alpha_1 / d_1 = \alpha_2 / d_2$.

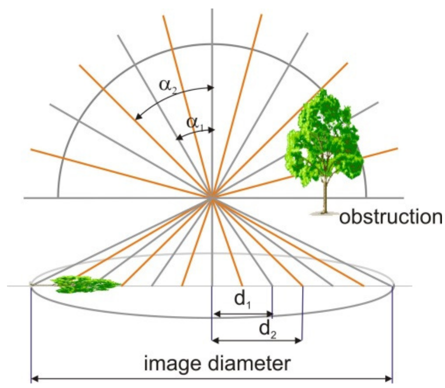

Fig. 2. Hemispherical projection model

Using the centred over the GPS measurement point and vertically orientated fish-eye lens there is an 180^0 picture of curtains in a polar coordinate system obtained. The origin of such coordinate system is in the center of a picture, which is an image of zenith and the polar axis determines the north direction. The angular picture coordinate is equal to the azimuth of an object point and the radial picture coordinate *d* is equal to $d = R / 90 * (90 - \sigma)$, where *R* denotes the radius of circular picture and σ is an elevation angle of object point in degree. The azimuth and elevation angle of terrain obstruction can be then easily derived from above relations, without any additional transformations. That is why hemispherical photography is a convenient tool for GPS site reconnaissance.

3. Case study

On the purpose of the efficiency of the proposed solution testing two measurements points (labeled D and K) were chosen. Each of these points characterized by the existence of obstructions in the form of buildings and trees. Point K was situated at a distance of about 70 cm from the wall of the building, which was at the south-east site of horizon. The building height reached 90^0 of elevation angle. That point was as well surrounded by 20^0–30^0 elevation height deciduous trees. The experiment was conducted at the end of December and January, when the trees were stripped of leaves. In the neighborhood of the point D was a building whose elevation height does not exceed 20^0. That point was also surrounded by coniferous trees below 25^0 above horizon, except for group of two, reaching 60^0, situated at north-east part of horizon pines. At each point the hemispherical, vertically orientated picture has been taken (Fig. 3).

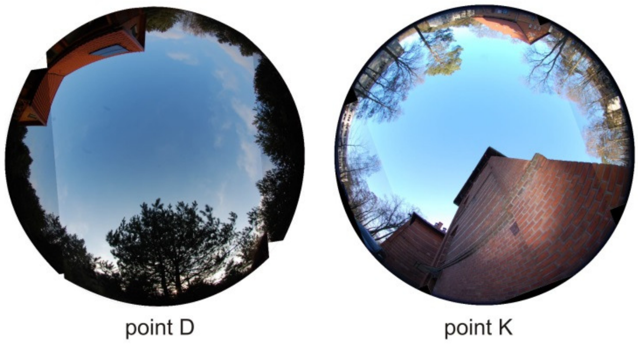

Fig. 3. Vertical fish-eye images of horizon above measurement points

For the picture digital Nikon D40 camera equipped with Sigma EX DG fisheye lens (focal length 8 mm) was used. The resolution of the image was 2000×2000 pixels. A very important issue is the orientation of the photo to the direction of the north. It was ensured by set on the north direction geodetic pole, the top of which was mapped in the picture.

For each point the 4-hour test time window was defined as follows: January 2nd 2014, from 11:15 to 15:15 UTC time for point D and January 4th 2014, from 11:00 to 15:00 UTC time for point K.

3.1. Hemispherical photography vs. tacheometry

The tacheometric survey of obstructions at each point was conducted. Leica TC300 tachometer was used. During tacheometry horizontal and vertical angles were measured. This task turned out troublesome to perform for two reasons. First of all, while determination of the building edge is easy, the determination of border between tree crown and the sky is confusing. Assumption that the whole crown is impenetrable obstruction is incorrect, especially if taking under consideration branches of deciduous trees defoliated. On the other hand it is extremely time consuming or almost impossible to measure each branch separately. The second inconvenience was related to technical trouble during pointing almost 90° height targets.

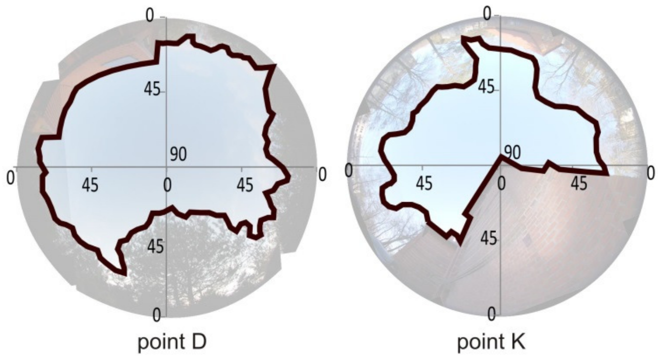

Fig. 4. Obstructions models from tacheometry

As it is visible in the picture (Fig. 4) the accuracy of mapping from the photography of objects as buildings is good enough for GPS measurement point obstructions determination. In case of complicated, irregular shaped obstructions like branches of trees, photographic method is even more convenient than tacheometry.

3.2. Image segmentation

To create a useful map of obstructions above GPS measurement point some segmentation of hemispherical image should be done. In case of obstructions determination, segments should be marked as *obstruction* or *open sky*, thus the *open sky* area should be determined and each pixel of this area should be converted into white (RGB 255,255,255). For this purpose manual or semi-automatic method is more convenient then simple thresholding because using automatic thresholding some bright object in the picture, like white wall for instance, could be wrongly recognized as an open-sky. In the presented experiment Corel Photo Paint X3 software has been used for determining *open sky* area and converting selected pixels into white. As a result hemispherical images with white sky were obtained (Fig. 5).

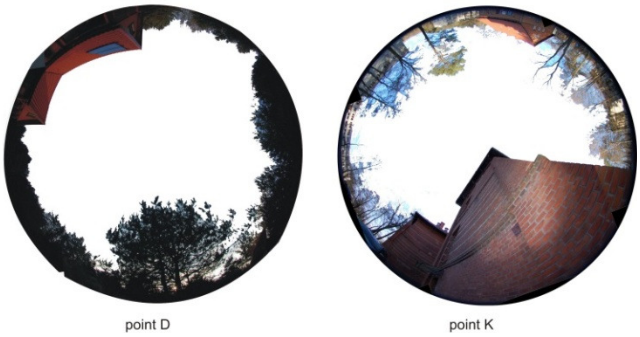

Fig. 5. Results of segmentation – sky converted into white

In the next step obtained previously pictures were converted into binary pictures (Fig. 6). For this purpose MatLab script based on the brightness thresholding algorithm:

$$g(x,y)=\begin{cases}1 if\ f(x,y)\geq T\\ 0 if\ f(x,y)<T\end{cases}, \tag{1}$$

where T is the threshold value set as RGB 255,255,255 was used. As a result of this conversion 2000×2000 size matrix, related to the binary picture was obtained. The matrix elements takes 0 for *obstruction* and 1 for *open sky* values.

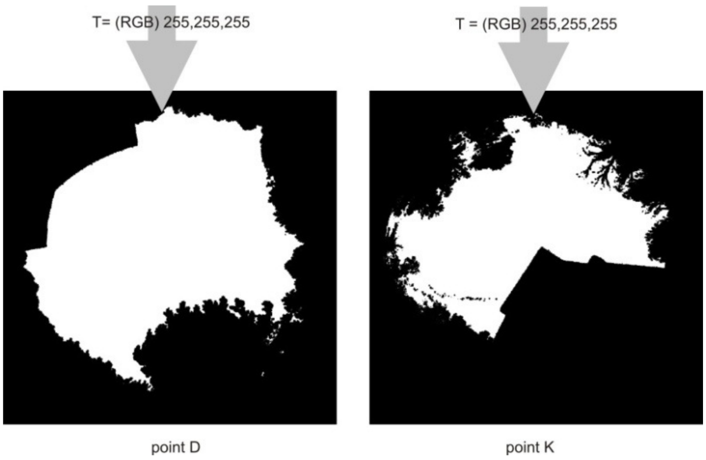

Fig. 6. Results of segmentation – binary picture

3.3. PDOP and svs Values

From the approximated values of the satellite orbital elements take from almanac, satellite position in geocentric coordinates system can be calculated. The unit vectors between sites and satellites can be computed using site and satellite coordinates. For the test time windows, topocentric coordinates as well as an azimuths and elevations of GPS satellites were calculated. For this calculations GPS almanac in YUMA format and approximated coordinates of measurement points were provided. The satellite positions calculated for consecutive epochs constitute satellites tracks As a result of superimposition of satellites tracks and obstruction models site satellite window diagram was generated (Fig. 7). The superposition was performed by MatLab script, deliberately developed for this purpose.

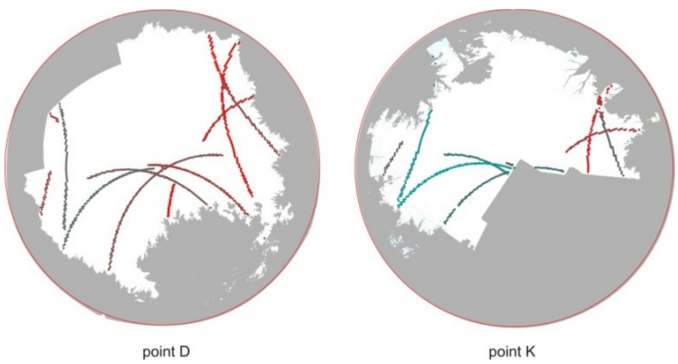

Fig. 7. Site satellite window diagrams for test times windows

More convenient for mission planning that site satellite window diagram is satellite visibility versus time diagram. Furthermore, the best indicator of satellite geometry is DOP coefficient. DOP is the geometry factor expresses composite effect of the relative satellite-user geometry on the GPS solution error [14]. Predicted values of DOP coefficients could be easily calculated from satellite azimuths and elevations angles [15]. Let us define **A** matrix as:

$$A = \begin{bmatrix} -cose_1 cosa_1 & -cose_1 sina_1 & -sine_1 & -1 \\ -cose_2 cosa_2 & -cose_2 sina_2 & -sine_2 & -1 \\ \vdots & \vdots & \vdots & \vdots \\ -cose_n cosa_n & -cose_n sina_n & -sine_n & -1 \end{bmatrix}, \tag{2}$$

where a and e denotes azimuth and elevation angle respectively. From the value of matrix **A**, covariance matrix **Q** as $\mathbf{Q} = (\mathbf{A}^T\mathbf{A})^{-1}$ could be found out. If the diagonal elements of **Q** matrix are q_{xx}, q_{yy}, q_{zz} and q_{tt}, PDOP can be equated as

$$PDOP = \sqrt{q_{xx} + q_{yy} + q_{zz}} \,. \tag{3}$$

Due to the variability of the constellation in time, PDOP value is time dependent, that is why PDOP versus time diagram should be presented. In order to present the influence of obstructions on the satellite visibility and PDOP value, the svs and PDOP diagrams with and without obstructions were generated (Fig. 8).

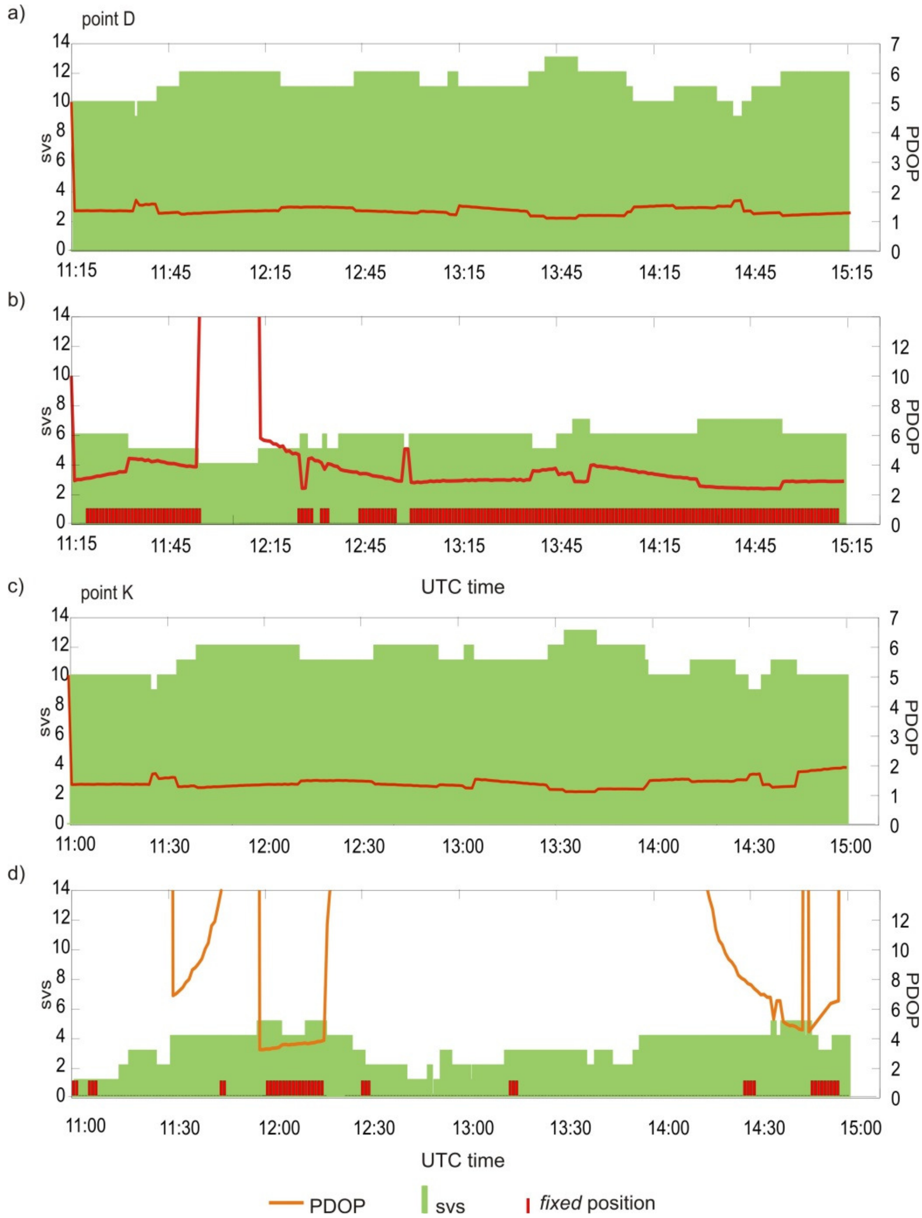

Fig. 8. Predicted svs and PDOP values diagrams for points D and K: a) and c) without considering the obstructions; b) and d) including the obstructions

As shown in Figure 8, there is just slight difference of svs and PDOP value between point D and K if obstructions were not considered. What is more, in this case, during all 4 hour time window the geometry of satellite constellation is excellent. Taking under consideration obstructions models the satellite availability and geometry are significantly worse. In case of point D there is one, approximately 20 minutes gap and two shorter gaps during witch there are adverse measurement conditions due to just 4 to 5 satellites available and high PDOP value. Because of the large ratio of the horizon obscuration at point K, there are just two time windows during witch measurement conditions are sufficient to precise GPS positioning.

3.4. RTK test measurement

In order to evaluate the efficiency of the proposed solution RTK measurements at points D and K were conducted. Measurements were performed with the use of Topcon HierPro geodetic, dual-frequency GNSS receiver. One four-hour observation session was planned and executed at each point. Time of measurements was the same as the test time window for which mission planning had been performed. Measurements were made using the GPS system. The following GPS parameters were assumed for all measurements: 1 second interval and 10^0 elevation mask, RTK method, RTK data provided by NAWGEO service of ASG-EUPOS system, VRS reference stations.

As a result of the experiment, the total of 14400 positions were obtained for each point, out of which 12788 (point D) and 1697 (point K) positions were obtained as a result of solving the ambiguity as the integer. The time in which those positions (of the fixed type) were obtained is marked on the diagrams (Fig. 8) as a red bar.

For the point D, relation between predicted measurement conditions and real possibility of fixed position obtaining can be easily noticed. In the case of point K this correlation is not so clear. It is probably because of the large ratio of horizon obscuration and multipath effect. At this point signals penetrating tree crowns (which crowns were treated in the model as obstructions) also were received during the measurement. Nevertheless, two windows of time, during which predicted circumstances are good enough for GPS positioning, could be easily indicated, and during that windows fixed positions were obtained.

4. Summary and conclusions

A preliminary results of using hemispherical digital photography obtained from fish-eye lens for advanced GPS mission planning have been presented in this paper. Hemispherical photography is a great tool for direct determining of a site satellite window diagram giving complete view of site. The accuracy of mapping from the photography is good enough for GPS measurement planning and in case of complicated, irregular shaped obstructions like branches of trees this method is even more convenient than tacheometry. The great advantage of the proposed method is that obstruction model is in any case made exactly at the point of measurement, which avoids errors caused by imprecise measurement station coordinates. Proper determination of GPS measurement point obstacles makes it possible to perform efficient GPS measurements even at hard observational conditions. In the future investigations some methods of automatic picture segmentation, especially in case of tree canopy should be developed.

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