Photogrammetric Potential of Digital Cameras in Handheld Gadgets for Digital Close Range Applications

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Abstract:
In recent years a large number of new low cost digital consumer cameras have appeared in the market. The aim of this paper is to describe a research undertaken to examine and evaluate the geometric stability of these cameras and their potential for photogrammetric use. For this purpose, three gadgets with cameras were chosen: two mobile phones and a personal digital assistant (PDA), all of them with built-in camera. Their geometric stability is examined using a test field, and the calibration parameters are determined. The calibration parameters’ results, such as the principal distance, principal point, radial and tangential distortion and their accuracies are given. The next step of the research was focused in the exterior orientation and the accuracies which can be achieved using stereopairs of the test field. The results were not discouraging at all and some important conclusions, for these three different types of cameras, are mentioned in the paper. Experimental research has been carried out using two study sites. The first is the fountain “Krini Priouli” at Heraklion of Crete and the second is the marble iconostasis of Saint Apostles in the Ancient Market of Athens. In both cases close-range photographs taken from the PDA were used. Results indicate that such cameras may be used in simple close – range photogrammetric applications, with relatively low accuracy requirements.

1. Introduction
During the last years, the manufacturers of mobile phones, decided to exploit the possibilities of digital technology, and to offer the opportunity of image recording using digital cameras via mobile phones. The collaboration of information technology and telecommunication companies constitutes the next step of mobile telephony development. In the near future rapid developments are expected. Already, mobile phone’s companies produced mobile phones, with embedded cameras, with resolutions over 3.5 and 5 megapixels (Mp). Also, since mobile phones tend to incorporate the characteristics of PDAs and vice versa, these gadgets are expected to replace all the others.

Using them in this way is promising, due to the fact that they are within reach of everyday’s user and also they are widely available. As a consequence a large number of images exists, taken with these handheld gadgets, not for photogrammetric purpose including and of course, monuments and archaeological sites. However, only few investigations of their metric ability exist (e.g. AB04).

In order to examine the potential of such handheld gadgets with build-in cameras, a performance evaluation of two different types of mobile phones and one PDA was carried out by the authors.

An important aspect of the usability of these cameras for photogrammetric purposes is their geometric stability and accuracy. Therefore the interior orientation parameters where determined using an accurately measured test field. Consequently, for evaluating the gadget’s accuracy and applicability, their cameras are put to test in everyday close-range photogrammetric applications.

2. Methodology

2.1 The handheld gadgets used
Three types of handheld gadgets were used for this study. The first was a Nokia 5140 mobile phone and the second was a Sony Ericsson K700i mobile phone both with built-in cameras. These mobile phone cameras
work at a resolution of 640 x 480 pixels. The third gadget was an HP iPaq 3700 PDA, with effective number of pixels 1.2, i.e. a resolution of 1280 x 960 pixels.

Figure 1: The handheld gadgets used

2.2 Description of the calibration process

From geometric point of view, a photograph is considered to be a central projection and more specifically a perspective one. This is actually the mathematical model that is used in Photogrammetry to represent the inverse process of the photography [P00].

The procedure of the determination of this mathematical model’s parameters, or generally what is called in the photogrammetric literature as interior orientation of a photograph, is called calibration of the camera [G98].

Generally, the accuracy of a camera’s performance depends on many and different factors, the most significant of which are: the resolution of the camera, the number of the photographs which are taken and use in the photogrammetric procedure, the geometry of the camera and the object and, last but not least, the geometry of the object itself.

Calibration parameters can be evaluated using many methods. Usually, when no-metric cameras are used, the calibration procedure is carried out with a test field [MFC*04]. For digital cameras the self-calibration method (using e.g. bundle adjustment) can be easily programmed to include any other errors from the CCD array sensor of the camera [S04].

The collinearity equations, including distortions and sensor errors, can be formed as [D95]:

\[ x = x_o - c \frac{A_{xy}}{TIN} + F_x \]
\[ y = y_o - c \frac{A_{yx}}{TIN} + F_y \]

Errors of the observed image coordinates can be analyzed further to:

\[ V_x = \Delta x + \Delta x_r + \Delta x_d \]
\[ V_y = \Delta y + \Delta y_r + \Delta y_d \]

Where:

\( x_o, y_o \): are for principal point
\( c \): is for principal distance
\( \Delta x, \Delta y \): are for radial distortion
\( \Delta x_d, \Delta y_d \): are for decentering distortion
\( \Delta x_a, \Delta y_a \): are for affine distortion

The extended collinearity equations, which are used in the bundle adjustment with self-calibration, may be formed as [R00]:

\[ \Delta x = \Delta x_r - \frac{2}{r} \Delta c - \frac{2}{r} \Delta a \frac{1}{x} \frac{x}{y} + \frac{2}{r} \frac{x}{y} + \frac{2}{r} \frac{x}{y} \]
\[ \Delta y = \Delta y_r - \frac{2}{r} \Delta c + \frac{2}{r} \frac{x}{y} + \frac{2}{r} \frac{x}{y} + \frac{2}{r} \frac{x}{y} \]

Where:

\( r = \sqrt{x^2 + y^2} \)
\( K_r, K_d \): are the radial lens distortion parameters,
\( P_r, P_d \): are the tangential lens distortion parameters,
\( S \): is the scale parameter
\( A \): is the affine distortion parameter

For calibrating the handheld gadgets the software “Calibration CCD” was employed, which was developed by the Lab. of Photogrammetry. Also, a test field consisting from 36 points with varying heights and a flat board containing 276 points, all of which were accurately measured a priori was used.

Figure 2: The test field used for calibration

The cameras settings such as zoom factor, focus, white balance etc. were kept constant during the calibration procedure. The calibration of each camera was performed up to 3 times. Also, in order to accomplish the maximum accuracy and to have favourable intersection angles, handheld gadgets were set so that the Base-to-Height ratio was equal approximately to 0.25 (where H is the taking distance and B is the base distance between
the two gadget stations). Figure 3 shows the handheld gadgets configuration for the camera calibration procedure.

![Handheld gadgets configuration](image)

**Figure 3: Handheld gadgets configuration**

2.3 Results of the calibration process

RMSEs of all performances carried out at the calibration process, were less than 0.5 pixels. Therefore image coordinates of calibration points were measured precisely. Mobile phone’s (resolution 640 x 480 pixels) and PDA’s (resolution 1280 x 960 pixels) photographs seem to have common characteristics at the calibration procedure.

No systematic variation of the calibration parameters were observed but only random variation has been recorded.

Evaluating the results, regarding to the principal distance, it was found out that Nokia 5140 mobile phone had the best performance and stability. Also PDA HP iPaq 3700 shows a good stability. Table 1 shows the results for the principal distance as calculated from the calibration procedure, and figure 4 the normalized range (with the image width) of changes of principal distance for each case.

<table>
<thead>
<tr>
<th>Handheld Gadget</th>
<th>Av. Principal Distance (pixels)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nokia 5140</td>
<td>750.37</td>
</tr>
<tr>
<td>Sony Ericsson K700i</td>
<td>734.25</td>
</tr>
<tr>
<td>HP iPaq 3700</td>
<td>1590.79</td>
</tr>
</tbody>
</table>

**Table 1: Average principal distance**

![Normalized range of changes in principal distance](image)

**Figure 4: Normalized range of changes in principal distance**

The changes of the principal point (referring to the image width) are shown in figure 5. Again Nokia 5140 mobile phone had the best results. Sony Ericsson’s camera shows random variation and instability.

![Changes of principal point (normalized to the image width)](image)

**Figure 5: Changes of principal point (normalized to the image width)**

Principal point at xx’ direction has larger distributed offsets from the center of the image, contrary to yy’ direction. This is recorded for all the photographs taken by handheld gadgets. Furthermore, standard deviations $\sigma_x$ are smaller than $\sigma_y$ as shown in table 2.

<table>
<thead>
<tr>
<th>Handheld Gadget</th>
<th>Standard deviations (pixels)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$\sigma_x$</td>
</tr>
<tr>
<td>Nokia 5140</td>
<td>4.49</td>
</tr>
<tr>
<td>Sony Ericsson K700i</td>
<td>21.58</td>
</tr>
<tr>
<td>HP iPaq 3700</td>
<td>19.55</td>
</tr>
</tbody>
</table>

**Table 2: Standard deviations of principal point**
The results of radial distortion for the two mobile phones used and the distortion curve of the PDA are shown in figure 6 and 7 respectively.

Tangential and affine distortions were evaluated from the calibration procedure, but they did not seem to have any important influence. So these, were consider not to be significant.

2.4 Accuracy with check measurements

The accuracy of the cameras may be evaluated comparing the photogrammetric results from the cameras with results which are more accurate [AB04]. Two stereopairs from each gadget were used in order to evaluate their accuracy.

Each photograph was imported at the Z/I SSK Image Station software. The relative orientation of each stereopair was determined. Several repetitions were carried out, in order to achieve the optimum accuracy.

With the removal of the y-parallax a stereo matching can be performed. For each stereopair more than 5 points were used and measured. The acceptance or not, of the results of relative orientation, depends on the remaining errors of the y-parallax. One should also consider the resolution of the images, the size of the measuring mark and the final accuracy desired [G98]. Table 3 shows relative orientation’s results for each stereopair.

### Table 3: Results of the relative orientation

<table>
<thead>
<tr>
<th>Handheld Gadget</th>
<th>Stereopair</th>
<th>Py (μm)</th>
<th>Max Py (μm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nokia 5140</td>
<td>1st</td>
<td>1.15</td>
<td>1.3</td>
</tr>
<tr>
<td></td>
<td>2nd</td>
<td>1.09</td>
<td>1.2</td>
</tr>
<tr>
<td>Sony Ericsson K700i</td>
<td>1st</td>
<td>1.22</td>
<td>1.9</td>
</tr>
<tr>
<td></td>
<td>2nd</td>
<td>0.31</td>
<td>0.6</td>
</tr>
<tr>
<td>HP iPaq 3700</td>
<td>1st</td>
<td>4.20</td>
<td>6.3</td>
</tr>
<tr>
<td></td>
<td>2nd</td>
<td>5.33</td>
<td>7.8</td>
</tr>
</tbody>
</table>

PDA HP iPaq 3700 presents the best results. This may be due to the highest resolution of the PDA. A similar accuracy was achieved from Nokia 5140 mobile phone, despite its low resolution. Large differences of the accuracy were recorded only from Sony Ericsson K700i mobile phone.

Moreover, 3D space coordinates of check points of the test field, were measured from stereoscopic observation for each stereopairs. These results were tabulated, and RMS of the difference in the measured coordinates, from stereoscopic observation and geodetic coordinates were calculated. Table 5 shows these results.

### Table 4: Absolute orientation results

<table>
<thead>
<tr>
<th>Handheld Gadget</th>
<th>Stereopair</th>
<th>RMS (in m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nokia 5140</td>
<td>1st</td>
<td>0.030</td>
</tr>
<tr>
<td></td>
<td>2nd</td>
<td>0.018</td>
</tr>
<tr>
<td>Sony Ericsson K700i</td>
<td>1st</td>
<td>0.016</td>
</tr>
<tr>
<td></td>
<td>2nd</td>
<td>0.051</td>
</tr>
<tr>
<td>HP iPaq 3700</td>
<td>1st</td>
<td>0.021</td>
</tr>
<tr>
<td></td>
<td>2nd</td>
<td>0.015</td>
</tr>
</tbody>
</table>
Table 5: RMS for the 3D coordinates

As it is shown, a relative accuracy of 1/400 in planimetry and 1/250 in heights may be easily achieved from Nokia 5140 mobile phone. However, Sony Ericsson K700i has the lowest relative accuracy, i.e. 1/150 in planimetry and 1/70 in heights. Higher resolution photographs taken from the PDA had a relative accuracy of 1/100 in planimetry and 1/50 in heights. Table 5, also indicates that it is possible to have a higher relative accuracy from the PDA’s camera.

The loss of accuracy, especially at distant objects from the camera is acceptable because of the low resolution of the cameras. This is also the main reason why good stereoscopic observation can be performed only in close range applications.

3. Experimental Results

After defining the calibration parameters and the accuracy of the handheld gadgets, experimental research had been carried out using two study sites. The first is the fountain “Krini Priouli” at Heraklion of Crete and the second is the marble iconostasis of Saint Apostles in the Ancient Market of Athens.

3.1 Fountain “Krini Priouli”

The fountain “Krini Priouli” was built in 1666 when general intendant of the area was Antonio Priouli. It is also known as “Krini Delimarkou”.

Figure 8: A photo of the fountain “Krini Priouli”

Two photos taken from the PDA HP iPaq 3700 were used. Again both interior and exterior orientation of the stereopair was prepared from SSK software. The results obtained, were similar to those from the test field for the specific camera. The exterior orientation’s RMS calculated was 0.033, 0.022 and 0.060 m for X, Y and Z respectively.

The 2D facade plan derived from the above stereopair, after digital stereoplotting, is shown at figure 9. Some problems occurred during stereoplotting at the detailed sections of the fountain such as the chapiters (drawn with dark lilac) due to the low resolution of the photographs.

Figure 9: The 2D façade of “Krini Priouli”

3.2 Marble iconostasis of Saint Apostles in the Ancient Market of Athens

The second study site chosen was the marble iconostasis of the Byzantine church of Saint Apostles in the Ancient Market of Athens. The iconostasis, which separates the holy altar and the main church, is decorated with marble reliefs [B94].

Figure 10: The church of Saint Apostles (left) and the marble iconostasis (right)
A stereopair of photos from the PDA were used. The same procedure, as “Krini Priouli” was applied for the marble iconostasis. A slightly better accuracy was achieved for the exterior orientation. The RMS calculated for X, Y and Z was 0.019, 0.022 and 0.021 m respectively. This may be due to the almost planar surface of the marble object. However stereoplotting problems occurred at the two parapets of the iconostasis, due to low resolution.

In figure 11 the 2D facade plan from the above stereoplotting (drawn with black) is shown and also a more accurate plan of the marble iconostasis, which was carried out combining both photogrammetric and surveying measurements (drawn with blue).

The low resolution of the cameras is the main reason of the low accuracy. Better results are expected in the near future from the next handheld gadgets generations, using higher resolution. Of course, a more conclusive evaluation requires further investigations, especially at the calibration process.

Reference


[D95] DERMANIS A., Analytical Photogrammetry, 1995


