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THE EFFECTS OF TEMPERATURE VARIATION ON SINGLE-LENS-REFLEX DIGITAL CAMERA CALIBRATION PARAMETERS

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ABSTRACT:

It is well known that temperature changes affect the geometric characteristics of cameras. Metric cameras, cameras specifically designed for photogrammetric work, are purposely built to maintain a stable geometry. However, the storage and working temperature variations can be very wide, whether the cameras are used for airborne or terrestrial observations. Even with metric cameras self-calibration is often used when the highest quality of results are being pursued.

The use of non-metric digital cameras particularly for terrestrial photogrammetric applications is not uncommon. The modern materials and the manufacturing quality of some digital cameras are now providing the photogrammetric community with great flexibility in lenses, camera bodies and functionality. With this the range of applications is expanding and for many organisations the ability to use a particular camera in this range of applications has made the investment in a digital camera more acceptable.

In many climates where the weather conditions can vary greatly and the cameras can be put through a wide range of temperatures even between the storage and the location for use. For example, storage may be in a 'warm' office environment and the working location could be an indoor but 'cold' building or outdoor sub-zero work place. The question that must be asked is 'what effect do these temperature changes have on the camera geometry?' Sometimes the application allows sufficient image geometry for a self-calibration, sometimes not. Should the cameras be allowed to 'acclimatise'? A number of questions can be raised related to variations in temperature.

This paper will investigate and aim to quantify, the effect of variations in temperature on modern single-lens-reflex (SLR) digital cameras from a series of trials. The results shown will be from the use primarily of Australis software and a calibration frame within the Institute of Engineering Surveying and Space Geodesy. Although, a range of cameras are available in the Institute concern over long term damage to the camera under trial has led to, initially, the use of a Nikon D100. Although this camera has been superseded it is still typical of many modern SLR digital cameras used for photogrammetric purposes.

1. INTRODUCTION

1.1 Background

It is well known that temperature changes affect the geometric characteristics of cameras. Metric cameras, those cameras specifically designed for photogrammetric work, are purposely built to maintain a stable geometry. However, for many cameras the storage and working temperature variations can be extremely wide, whether the cameras are used for airborne or terrestrial observations. Even when metric cameras are being used, in-situ self-calibration is often employed when the highest quality of results are being pursued.

The use of non-metric digital cameras, particularly for terrestrial photogrammetric applications, is becoming common place. As the main market for these cameras is on the high street, there is a wide range of options available. The modern materials and the manufacturing quality of some digital cameras are now providing the photogrammetric community with a greater flexibility in lenses, camera bodies and functionality. This has led to the range of applications expanding and the investment in a camera and accessories more affordable for many organisations.

Labe and Forstner (2004) conducted research into low-cost digital consumer cameras for photogrammetric measurement needs. They stated: "An important aspect of the suitability of these cameras is their geometric stability. Two aspects should be considered: The change of calibration parameters when using the camera's features such as zoom or auto focus and the time invariance of the calibration parameters." The conclusions they reached through these investigations using a range of low-cost consumer digital cameras were that these cameras can be used for photogrammetric purposes but only under certain limited accuracy requirements.

However, one of the biggest concerns for the use of these cameras for photogrammetry is stability of the geometry. This is not normally an issue for the casual user where they are primarily interested in high quality images rather than geometry. In many climates where the weather conditions can vary greatly the cameras can be experiencing a wide range of temperatures

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even between the storage and the location for use. For example, storage may be in a 'warm' office environment and the working location could be an indoor but 'cold' building or outdoor sub-zero work place.

The question that must be asked is 'what effect do these temperature changes have on the camera geometry?' Sometimes the application allows suitable image geometry for an in-situ self-calibration, but sometimes not. Should the cameras be allowed to 'acclimatise'? A number of questions can be raised related to variations in temperature. Although it is well known in the photogrammetric community that temperature variation do affect the geometry and therefore the quality of results that can be achieved there is little evidence that scientific trials have been undertaken to fully justify these views. For this reason this research was undertaken to try and quantitatively support commonly held views.

The modern cameras are made of a variety of materials; plastics metals, and glass. Both exterior and interior components will be affected by temperature changes and will both have a potential influence on the camera characteristics. So it is important with trials of this kind to monitor the internal and external temperature of the camera. The difficulty with monitoring the internal components is the lens must be removed to perform this task which has the knock-on effect of affecting the camera parameters.

The techniques employed to determine the geometric parameters of the camera in the laboratory or in-situ when using digital cameras, are very similar to those techniques used on analogue cameras with only slight modifications in techniques required. In the case of this project; a wide angle lenses is used which can result in large lens distortion characteristic.

1.2 Aims and objectives

The aim of this research is to investigate if changes in temperature have an affect on the stability and accuracy of geometric characteristics of digital single lens reflex cameras used for photogrammetric purposes.

Objectives:

1. To investigate the magnitude of the typical variation in camera calibration values associated with removal and replacing the lens. This will provide values that can be taken into account when assessing results from objective 2.
2. To investigate how the changes in temperature of the camera will affect the camera calibration values.

Methodology:
The methodology is based of the following stages:

1. Undertake a series of calibrations using Australis software and the existing camera calibration frame in the IESSG to determine the effect of removing the lens.
2. To carry out calibrations on a DSLR camera with a lens of fixed and standard focal length, with temperature change of both lens and camera.
3. Temperature will be varied by putting the camera in a fridge for a long period of time and undertaking calibration trials at intervals as the camera warms up in a room environment.
4. Plot values of the main camera calibration parameters against temperature.

2. TECHNOLOGY

A range of cameras are available within the IESSG but concern over long term damage to the camera due to the extremes of temperature (outside the recommended working range) resulted in the use of an old Nikon D100. Although this camera has been superseded it is still typical of many modern SLR digital cameras used for photogrammetric purposes.

2.1 System hardware

The images were captured using a Nikon D100 digital SLR camera with a focal length of nominally 28mm, a 7.8 µm pixel size and a sensor size of 3008x2000pixels.

Figure 1. Nikon D100 camera used in the trials

Figure 2. Nikon D100 and ring flash attachment

It was decided that a fixed 28mm should be used with the Nikon D100 camera body. This is a typical wide angle lens used with the camera for photogrammetric applications. With no zoom being present this lens offers stability and high accuracy.

A high powered Sigma ring flash was used to illuminate the retro reflective targets on the calibration frame. The ring flash itself was held and not attached to lens, to prevent the weight of it pulling the barrel of the lens down and affecting results. The calibration is dealt with in section 2.2.

In order to measure the surface temperature of the camera and lens a standard thermometer could not be used. In this case a 'Testo 810' air and surface temperature meter was used, see figure 3. It is a 2-channel temperature measuring instrument, with an infrared thermometer using a laser measurement spot, recording the air temperature and simultaneously the surface temperature without contact.

Figure 3. Testo 810 infrared temperature gauge

In order to assess the reliability of this measurement device and find out exactly what temperature the laser was recording it was necessary to undertake a few simple experiments. The main concern was when taking measurements on the lens, and in particularly the glass. Was the temperature displayed the reflected temperature or was it penetrating all the way through the lens and recording the temperature of what was behind the lens, namely the camera body interior?

The procedure adopted here was to remove the lens from the camera body and shine the laser through the lens and out the other side with the operators hand placed behind the lens. The skin temperature of the operator was recorded before this took place and was seen to be much hotter than that of the lens glass. It was shown in all cases that the temperature recorded was from the glass itself and not a result of penetrating through the lens and recording the temperature of the object behind it. This also means temperatures recorded from the interior of the camera body on the mirrors were also reliable.

2.2 Camera calibration

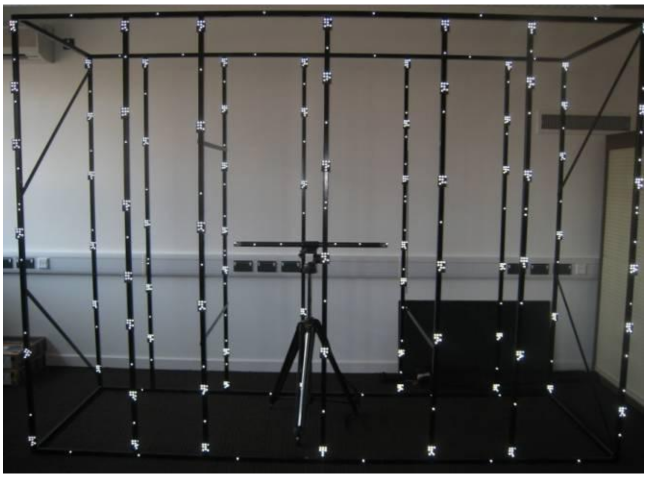


Figure 4. Camera calibration frame

Figure 4 show the laboratory camera calibration frame. There are approximately 83 reflective coded targets on the frame, with over 100 single reflective spot points. Each coded target has a unique pattern and automatic target recognition and measurement is used. A scale bar is available when required and it can be seen in figure 4 supported on a tripod.

Australis v7.13 software (Photometrix, 2010) is used to undertake the automatic target measurement and generate camera calibration parameters and quality statistics.

3. TRIALS, RESULTS AND ANALYSIS

3.1 Test procedure

During the trials the temperature of both the internal components and external components of the camera were to be recorded. Figure 5-9 shows where temperatures are recorded before each calibration. The temperature is recorded at 3 points and averaged.

Figure 5. Temperatures are recorded at the interior locations indicated

Figure 6. Temperatures are recorded at the exterior locations indicated

Figure 7. Temperatures recorded on the outside of the lens

Figure 8. Temperatures recorded on the exterior of the lens casing

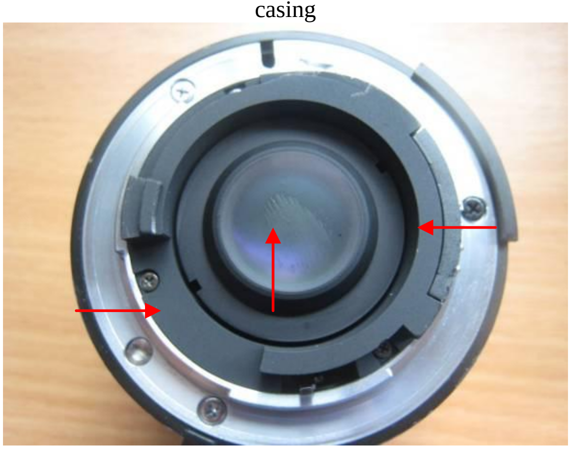


Figure 9. Temperatures recorded on the interior of the lens

The camera was cooled by placing it in a plastic bag to protect it from moisture and then placed in a refrigerator for 12-14 hours. The battery and memory card were removed prior to cooling.

The experimental procedure for the calibration was as follows: 32 photos were taken for each calibration, in sets of 4 images. A set consisted of images from the same location but rotating the camera through 90 degrees between each photo. This strengthens the geometry, and helps reduce correlation between the parameters. The images were taken at two distances from the frame and at various heights to again strengthen the geometry.

Camera Settings:

Shutter speed = 1/250	Stop value = F11
Image speed = ISO 100	The images were stored as Jpegs
Flash = 1/8 Power	

3.2 Trials

3.2.1 Trials to investigate the effect of removing the lens on the calibration parameters

Procedure; date of trial 17 February 2010:
a) To investigate general stability of calibration values. Not removing lens between each calibration
b) To investigate the effects of removing lens between each calibration so this effect can be taken into account when there is a need to remove the lens to measure internal temperatures

3.2.2 Trials to see the effect of temperature

Procedure; date of trial 18, 22, 23 February 2010 (trials (1, 2, 3 respectively) were undertaken a number of times to monitor consistency):
To investigate the effects of temperature the lens was removed between each calibration in order to record interior temperatures

- Temperatures taken before each calibration (including interior locations)
- Calibration carried out using standard 32 photo procedure explained above
- Repeated every 10 mins as temperature of the camera increases, until reaches approximate room temp.
- Jpeg files uploaded to Australis for analysis

3.3 Results, Analysis and Discussion

All temperatures are given in degrees Centigrade and all distances/coordinates are in mm unless otherwise stated.

3.3.1 Trials to investigate the effect of removing the lens on the calibration parameters

Trial No	1	2	3	Mean	Range
C mm	28.9114	28.9198	28.9229	28.9180	0.0115
Xp mm	0.2606	0.2610	0.2642	0.2619	0.0036
Yp mm	0.0439	0.0423	0.0420	0.0427	0.0019
K1 x E-4	1.4915	1.4952	1.5385	1.5084	0.0470
K2 x E-7	-2.5001	-2.3899	-2.9140	-2.6013	0.5421
K3 x E-10	4.2826	3.0689	6.0497	4.4671	2.9808
Rad Dist µm @ 14.25 mm	336	329	346	337	17

Table 1. Repeating the calibration without removing the lens

Table 1 shows the variation in the parameters for 3 calibrations without removing the lens. As can be seen the range in the values is relatively small compared with the range of values obtained from the temperature trials, figures 11 to 13.

Table 2 shows the results from 3 calibrations when the lens is removed and refitted after each calibration. The radial lens distortion remains relatively stable as might be expected and so does the focal length considering results in table 1. The Xp and Yp values change a small amount particularly the Xp value, this might be expected as it is difficult to very accurately relocate the lens. The magnitude is interesting when compared with figure 12 as the magnitude would not compensate for the large change when the temperatures are low.

Trial No	1	2	3	Mean	Range
C mm	28.9132	28.9240	28.9247	28.9206	0.0115
Xp mm	0.2969	0.2881	0.2703	0.2851	0.0266
Yp mm	0.0364	0.0360	0.0408	0.0377	0.0048
K1 x E-4	1.5150	1.5613	1.5800	1.5521	0.0650
K2 x E-7	-2.6603	-2.8138	-3.1204	-2.8648	0.0460
K3 x E-10	4.8365	4.5711	6.2243	5.2106	1.6532
Rad Dist µm @ 14.25 mm	340	341	348	343	8

Table 2. Repeating the calibration with removing the lens between calibrations

3.3.2 Trials to see the effect of temperature

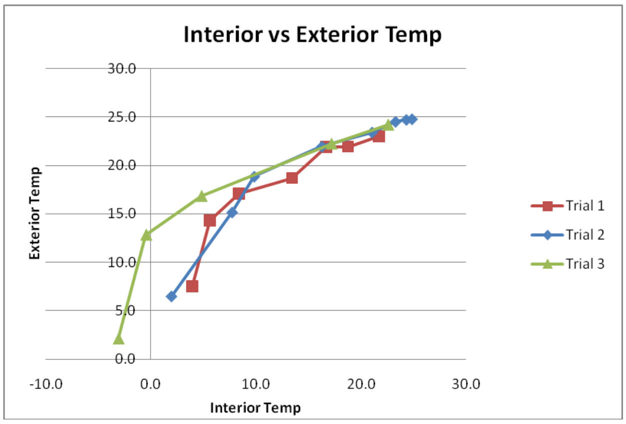


Figure 10. Interior and exterior temperatures

Figure 10 shows the importance of monitoring the internal camera temperatures where the external parts have warmed up a lot quicker than the internal parts. The internal warming is therefore more important than the external temperature for monitoring changes and will be used for the analysis.

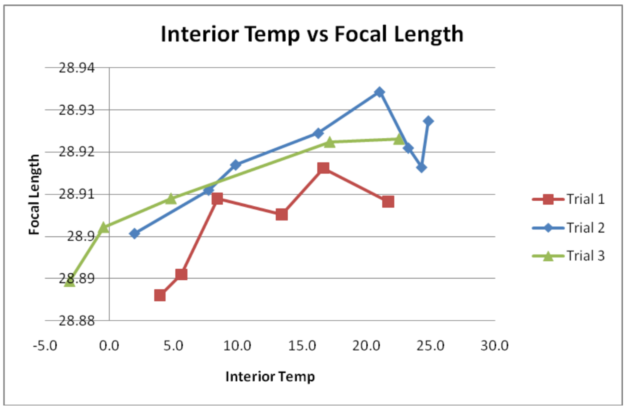
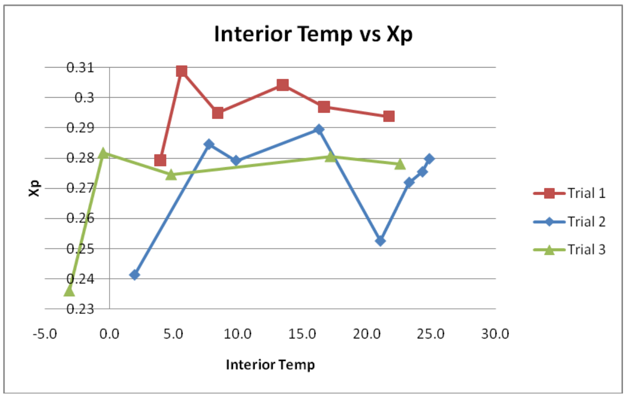


Figure 11. Effects of interior temperatures on the focal length

Figure 11 shows that a temperature change of about 30degrees makes a change in the order of 0.03mm in a reasonably linear way. This equates to approximately 0.01mm per 10degrees.



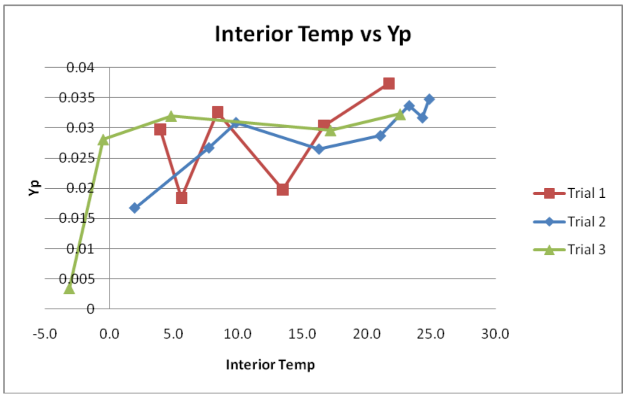


Figure 12. Effects of interior temperatures on the position of the principal point of auto collimation

Figure 12 shows that there are some relatively large changes in position (Xp, Yp) when the temperature is low, less than 5-10 degrees. The Yp values show a small increase as the temperature increases but the Xp values are variable but relatively stable.

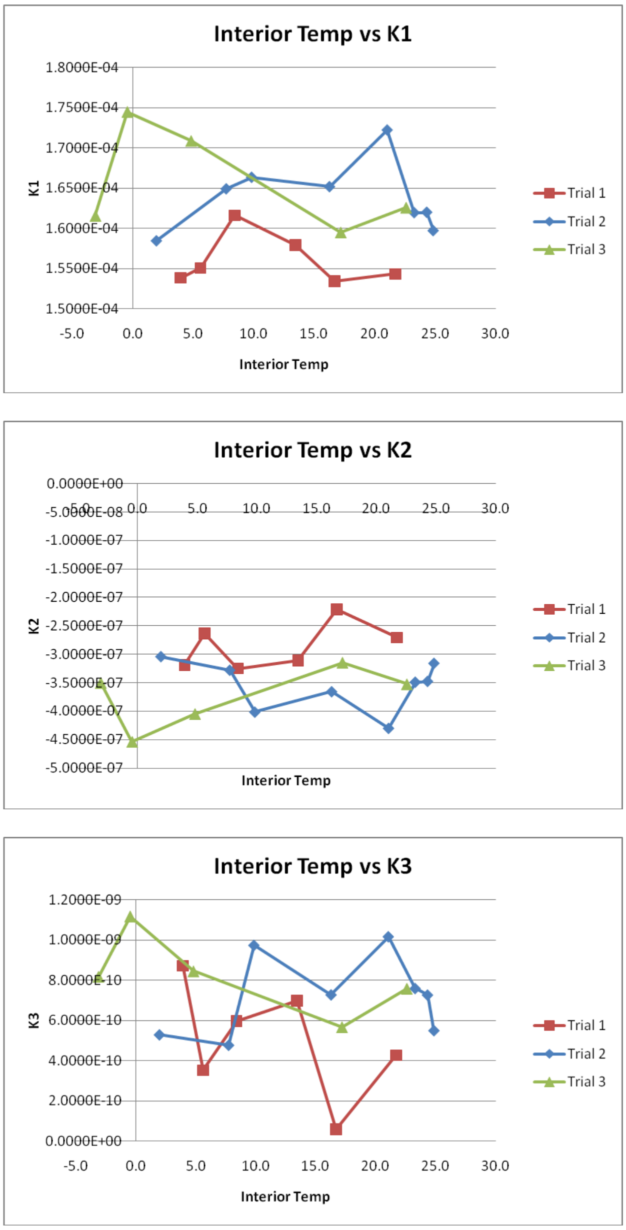


Figure 13. Effects of interior temperatures on the radial lens distortion parameters

Although the graphs of temperature against K1,K2,K3, figure 13, show some variations they do not seem to correlate against the temperature changes. This is what we might be expected, that the lens structure is not affected by the change in temperature.

The results show that temperature is having an effect on the camera geometry and calibration parameters that are computed. Trials are continuing to further qualify the effects of removing and refitting the lens and the effects of the variation in temperature.

4. CONCLUSIONS

The results show that internal temperature must be recorded to get a correct indication of the temperatures of the camera body that will affect the camera calibration parameters. The graphs of the temperature against individual parameter values show that the focal length and the position of the principal point do have a systematic relationship. The results do not show this is the same for the radial lens distortion parameters.

This shows that where the highest quality results are to be achieved in-situ calibration or calibration at the 'working' temperature are beneficial.

5. REFERENCES

References from Other Literature:
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5.1 Acknowledgements

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