Digital near-infrared camera for 3D Spatial Data Capture

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ABSTRACT

Low-cost, medium-resolution and hand-held digital cameras with near-infrared (NIR) capability are now readily available. The NIR spectrum (700 to 925 nanometers) is a tiny part of the overall electro-magnetic spectrum. It's just outside the spectrum seen by the human eye. While it is not possible to see NIR radiation it can be recorded on NIR films or CCDs with special filters. Digital NIR image of vegetations, living things, rocks and man-made objects have a number of positive features over the traditional color or black and white photography. In the past, NIR images were strategically used only because of the expensive and hard-to-find NIR films and high-cost CCDs. However, present CCD cameras require only inexpensive NIR filters to take good NIR images. The paper highlights the current applications and potential of NIR images in photogrammetry. Next, the paper provides discussion on the calibration of digital cameras which could be used for high precision 3D photogrammetric work.

Key words and phrases: Near-Infrared photograph, 3D spatial data, Camera calibration, human tissue

1.0 INTRODUCTION

The NIR spectrum (700 to 925 nanometers) is a tiny part of the overall electro-magnetic spectrum (figure 1). It's just outside the spectrum seen by the human eye. While it is not possible to see NIR radiation it can be recorded on NIR films or CCDs with special filters. By and large, most photographed NIR radiations are reflected from the photographed objects. The original radiations sources are the sun, artificial lights or artificial emitters or a combination of these sources. To provide a uniform illumination of the object in a room, a NIR light source is built into the flash unit in digital cameras. In the past NIR images were strategically used only because of the expensive and hard-to-find NIR films. However, CCDs has created a low-cost and user-friendly approach of getting high-resolution NIR images.

Low-cost nigh-shot cameras are capable of taking good NIR photographs up to 1.1 μm without any complicated setup. Generally, the NIR cut-off filters are removed to increase the sensitivity under dark conditions. To remove the visible bands (up to 840 nm from NIR photograph IR filters are mounted in front of the camera lens. The photography is similar to Moderate Resolution Imaging Spectroradiometer (MODIS) band 2 (841-876 nm; Kinoshita, et al 2003). For proper daylight aerial photography of terrain neutral density (ND) filters are also needed to reduce solar reflection. The photographs are similar to satellite imagery. In general, NIR photographs are digital processed to highlight the underlying features. Off-the-shelf image processing software may be used to produce good composite photograph. For an example it is possible to highlight both colour and NIR photographs by editing the channels so that a less important channel such as the blue in the colour photograph would be replaced by the NIR image. A display of all the channels of the new colour composite reviews the old red, the old green and the new NIR features.

The paper provides a summary of the current applications of small-format NIR images in photogrammetric mapping of the environmental and medical fields. Additionally, the paper provides a discussion of the research carried out recently. The research involves the calibration of NIR cameras and the penetration depth of NIR using vegetable dyes.

1.1 Environmental Applications

Application of small-format CCD in this very broad discipline is probably the most noteworthy. Generally, the photogrammetrists are requested to map and study the vegetation, water quality and soil or rock characteristic of the terrestrial and the marine environment. NIR aerial photography is an important tool in the study of changes to the environment; the pollution of the air and water; the health of crops, forests, wetlands and the sea; and the condition of the soil (Jackson 1986; Kinoshita et al 2003; Wright et al 2003; Kodak 2004). The advantage of NIR is its ability to penetrate aerial haze (*ibid)*.

Most documentation of the terrestrial environment involves the use of CCD cameras and aerial photography. In a routine practice, both colour and NIR photographs are captured at a suitable altitude. The mapping entails either digital mapping or digital orthophoto production or both from the aerial photos. The convenience of CCD for NIR photography has resulted in the extensive use of the invisible light radiant.

1.2 Biomedical Applications

Eggert (1935) was among the first scientists to discover that oxy and carboxyhaemoglobin could be differentiated with NIR photographs. His research showed that oxyhaemoglobin reflects more while carboxyhaemoglobin absorbs more NIR radiation than the surrounding tissues (Nieuwenhuis 1991). Nieuwenhui (1991) and Cotton et al (1999) showed that in the epidermis or the upper layer of the skin the NIR radiation is absorbed by the pigment melanin. In other words, any abnormality of the skin could be detected without any invasive intervention. Recently, NIR spectroscopy have been researched to determine the optimum wavelength(s) and the most appropriate technique for the study of the concentration of oxyhemoglobin (HbO_2) and deoxyhemoglobin (HbR) in blood vessels (Strangman et al 2003). The potential of the studies includes non-evasive study of the characteristic of blood circulation (flow pressure, flow volume) and vascular condition which includes obstruction and congestion.

2.0 METHODOLOGY

2.1 NIR/colour camera lens calibration

For ultra-high precision 3D spatial data capture using images the cameras must be calibrated. Standard non-metric camera calibration is well documented (Fryer, 1989; Beyer 1992; Peterson *et al*. 1993; Fraser and Edmundson 1996). This process includes the determination of the principal point of autocollimation (PPA), the principal distance (PD), the radial lens distortion parameters (k_1, k_2 and k_3), and in some instances the dynamic fluctuation.

2.1.1 Procedure

In the research cameras were calibrated using a calibration device at the School of Surveying (figure 1). The position of the camera mount and the target board were adjusted so that the object-distance of 700 mm would be similar to the object-distance of the stereophotography. The PD was set to a wide-angle setting of 28.0 mm. The zoom ring was taped securely so that the focal length was fixed for the entire exercise. The Camera F-stop was set at 2.0. The small value (default value) ensured the use of higher shutter speed. The camera was positioned at the camera mount and the target board was photographed with a high precision Invar bar in the middle of it. The target board was rotated to allow four convergent photographs to be taken for a self-calibration. In addition, the camera was rotated along its z-axis by 90 degree to allow four more convergent photographs to be taken. Five sets of eight convergent photographs were obtained for the exercise. All the convergent photographs were digitized automatically using Australis (camera calibration software developed at the University of Melbourne, Australia). Self-calibration technique was used because the technique does not require a set of known ground coordinates of the targets photographed (Cooper and Robson 1996:p38).

2.2 Depth of NIR penetration tests.

For the majority of NIR applications in the medical field involves the penetration of NIR radiation in human tissue. As discussed earlier NIR is known to penetrate skin to a depth exceeding 3mm. However the correct wave-band and image processing techniques must be used to obtain the optimum results. The objective of the exercise is to establish the correct procedure.

2.2.1 Procedure

Vegetable colour dyes (pigment) were used in the study. Plate glass was painted with black dye and NIR-reflective objects were placed behind the plate glass. Two Sony digital still-frame cameras Cyber-shot DSC-F828 were used in the test. Pairs of Stereo-NIR photos were taken to determine the depth of the NIR penetration. DVP digital photogrammetry workstation, developed by DVP-GS, Canada, was used to digitize the craniofacial stereomodel in stereoviewing mode. The exercise was repeated using red dye.

3.0 RESULTS AND ANALYSES

3.1 NIR camera calibration

The results of the camera calibration exercise are provided in Table 1. The principal distance (PD) of color photography is shorter than the PD of NIR photography by about 210 microns. The standard deviation of the computed PD of the NIR photography is twice larger than that of the color photography. A statistical student t-test ($Z_\alpha(0.05)$) shows that the difference between the means is significant (H_0: μ_1-μ_2 = 0 was rejected). Consequently, it is essential to calibrate NIR photography.

Table 1. Calibrated principal distance of Sony Cyber-shot DSC-F828.

Photograpl	Set 1	Set 2	Set 3	Set 4	Set 5	Mean	Std. De
NIR (mm	29.28	29.291	29.28	29.18	29.28	29.26	0.045
Color (mm	29.03	29.077	29.04	29.05	29.06	29.05	0.018

3.2 NIR penetration depth

Only preliminary results are available at this stage (Table 2). Black dye absorbs the NIR more readily than red dye. Subsequently, deeper penetration was achieved by red dye. The NIR-filter used was Warren #93. A range of filters will be tested in future research.

Table 2. Depth vs color of dye

Photograpl	Set 1	Set 2	Set 3	Mean
Black	0.6	0.9	1.1	0.9
Red	1.2	1.5	1.4	1.4

4.0 CONCLUSIONS

This paper attempted to determine whether digital NIR camera could be used for high accuracy depth measurement based on the NIR penetration capability in human tissue. The results show that the potential is good. More research is needed to establish the correct wave-band filter and image processing technique in order to achieve optimum penetration measurement.

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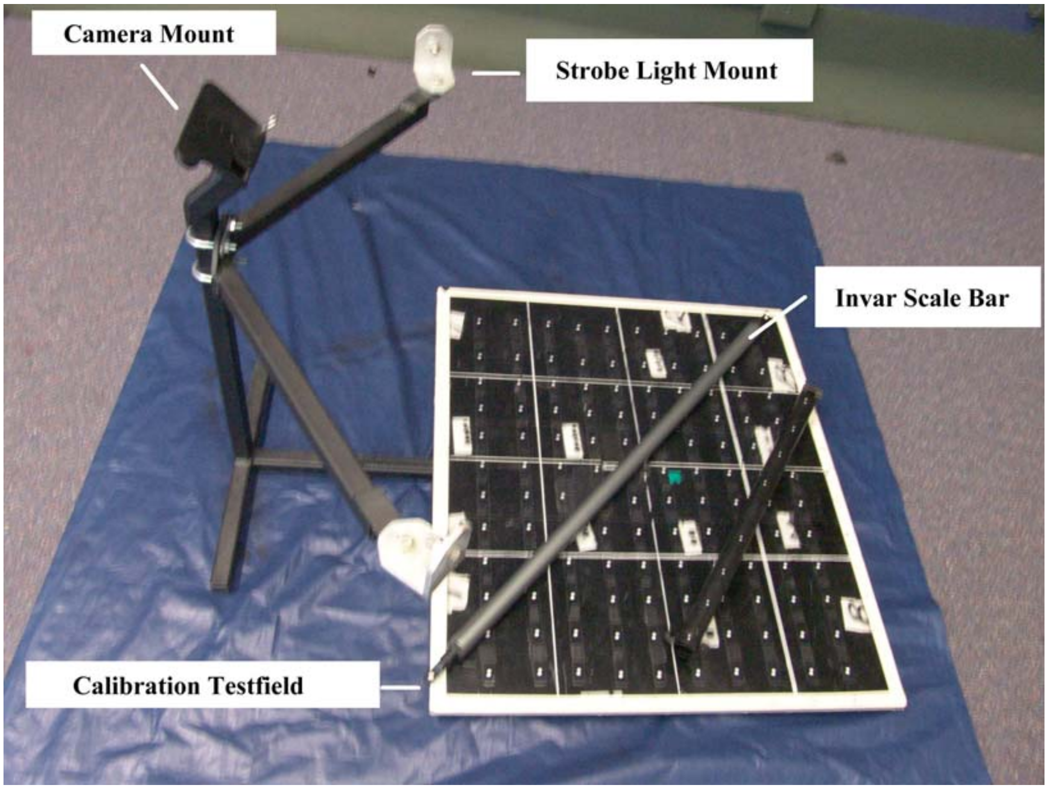

Figure 1. Camera calibration device. Note that a variety of calibration testfields could be design for the device.