FIG WORKING WEEK 2017

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Correction of Terrestrial LiDAR Data Using a Hybrid Model (8547)

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Presentation Outline

- ❑ Introduction
- ❑ Experimental Procedure
- ❑ Results & discussion
- ❑ Conclusion & future research areas

Introduction

- Utilization of Terrestrial Laser Scanning (TLS) intensity data in various studies e.g.
  - Change detection
  - Deformation monitoring
  - Material classification
- Radiometric correction of TLS data is an important step in data processing.
  - Reduce the error in the data
- In this paper, a hybrid method for correcting intensity data has been presented.

Introduction

- The proposed hybrid method aims at addressing two issues:
  - Near distance effects for scanning measurements taken 1 to 6 metres
  - Target surface roughness as expounded in the Oren-Nayar reflectance model

- The proposed hybrid method has been applied to correct concrete intensity data that was acquired using the Leica HDS7000 laser scanner.

- The results of this proposed correction model are presented to demonstrate its feasibility and validity.

Why Correction of Intensity Data?

- Essential due to systematic effects in the LiDAR system parameters and measurements and in order to ensure the best accuracy of the delivered products (Habib *et al.,* 2011).

- Convert the laser returned intensity recorded by the laser scanner to a value that is proportional to the object reflectance.

- A standard intensity correction method that can be applicable for all the various types of laser scanners is non-existent (Penasa *et al*., 2014).
  - However, in Tan and Cheng (2015), it is purported that the proposed intensity correction method is suitable for all TLS instruments.

Why Correction of Intensity Data?

- Some of the laser scanning research work are still being published without the intensity data having been corrected (Krooks *et al.,* 2013).

- In the case of Airborne Laser Scanning (ALS), the subject of intensity data correction has an old history compared to TLS (Kaasalainen *et al.* 2011).

- Correction of TLS intensity data is still an open area of investigation.....

Aim of Study

- Modelling the variables that have an effect on the intensity values of the laser in this case the effects of the measurement range and incidence angle.

- Investigation focused on using existing models of laser behaviour to develop a correction model for TLS intensity data that is also capable of addressing near-distance effects and surface roughness of the target.
  - Not all objects are perfect Lambertian reflectors

- The proposed hybrid intensity correction method is based on the radar equation (Jelalian, 1992), near-distance correction model (Fang *et al.*, 2015) and the Oren-Nayar reflectance model (Carrea *et al.*, 2016).

Experimental Procedure

Target Objects: Concrete Specimens

- Prismatic concrete beams (Fig. 1) were used as scanning target objects.
- Surface roughness of the scanned object was of interest in this study.
- For easy identification, the concrete specimens were labelled as: Block C, Block 1, Block 2, Block 3 and Block 4.

Fig. 1: Concrete specimens

Why concrete was used?

- Widely used construction material
- Many structures are made of concrete
- On-going study of fire-damaged concrete
- Change detection of concrete structures

Experimental Procedure

Scanning Room and Equipment

- Experiments were conducted under controlled laboratory conditions. The factors affecting the returned intensity under such conditions are the scanning geometry and the instrumental effects.

- Since the experiments were carried out in a controlled environment and at short range (1 to 6m), atmospheric losses were neglected.

- The Leica HDS7000 laser scanner (Fig. 2) was used to scan the concrete specimens and the technical specifications of this scanner are as presented in Table 1 below.

Experimental Procedure

Equipment Used

Fig. 2: HDS7000 Scanner

Table. 1: Specifications Scanner

Scanner	**Leica HDS7000**
Ranging method	Phase
Wavelength	1500nm
Field of View (Ver/Hor)	320˚ x 360˚
Laser Class	1
Range	0.3-187m
Linearity error	≤1mm
Samples/sec	1016000
Beam diameter	~3.5mm @ 0.1m
Beam divergence	< 0.3 mrad
Temp Range	0-45˚C
Colour	External
Weight	9.8kg

Experimental Procedure

Measurement Setup and Data Acquisition

- The measurement distances between the HDS7000 scanner and the target objects (concrete specimens) were ranging from 1 to 6 metres.
- The steel frame where the blocks were placed was levelled using a spirit level.
- Distances up to 6m in steps of 1m were measured using a total station so as to have scans taken from well-known accurate distances. The geometry of the experiment in terms of scanning measurement setup is shown in Fig. 3.

Measurement Setup

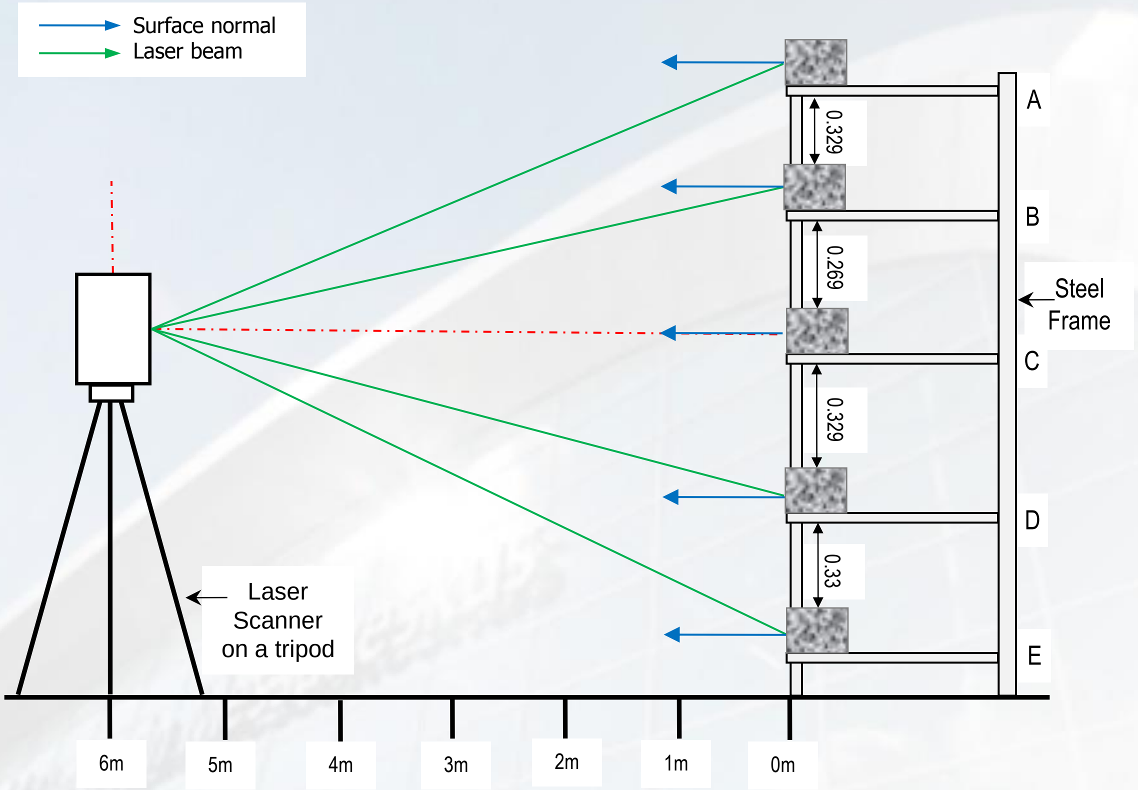


Fig. 3: Laser scanner and blocks at different levels on a frame (Letters *A*, *B*, *C*, *D* and *E* stand for shelf levels).

Data Processing

Scan Data Pre-processing

- The HDS7000 scans were converted to text files (.pts format) using the Z + F laser control software.
- The scans which were converted to text files contained the geometric data in terms of X, Y and Z coordinates in a Cartesian coordinate system as well as radiometric data i.e. the intensity values for the 3D coordinates.
- The intensity values of data converted to text files were ranging from -2047 to +2048.

- The output Cartesian coordinates can be converted to spherical (range, zenith and azimuth angles) coordinates based on a zero origin for the TLS instrument as described in Eq. (1) (Soudarissanane *et al.,* 2009):

$$\begin{bmatrix} R_i \\ \theta_i \\ \phi_i \end{bmatrix}_{i=1....n} = \begin{bmatrix} \sqrt{x_i^2 + y_i^2 + z_i^2} \\ \tan^{-1}\left(\frac{y_i}{x_i}\right) \\ \tan^{-1}\left(\frac{z_i}{\sqrt{x_i^2 + y_i^2}}\right) \end{bmatrix}_{i=1......n} \quad [1]$$

Intensity Data Correction

- Radar (range) equation

$$P_r = \frac{P_t D_r^2}{4\pi R^4 \beta_t^2} \eta_{sys} \eta_{atm} \sigma \qquad [2]$$

Where P_r is the received power, P_t is the power transmitted, D_r is the receiver aperture, R is the range between the scanner and the target, β_t is the laser beam width, σ is the cross-section of the target, η_{sys} and η_{atm} are system and atmospheric factors respectively.

The cross-section σ can be described as follows:

$$\sigma = \frac{4\pi}{\Omega} \rho A_s \qquad [3]$$

Where Ω is the scattering solid angle of the target, ρ is the reflectivity of the target and A_s the area illumination by the laser beam. Under the following assumptions Eq. (3) can be simplified. First, the entire footprint is reflected on one surface and the target area illumination A_s is circular, hence defined by the range R and laser beam width β. Secondly, the target has a solid angle of π steradian (Ω = 2π for scattering into half sphere). Thirdly, the surface has Lambertian scattering charateristics. If the incidence angles are greater than zero (α > 0°), σ has a proportionality of cos α (Höfle and Pfeifer, 2007):

$$A_s = \frac{\pi R^2 \beta_t^2}{4} \qquad [4]$$

Substituting A_s in Eq. (4) into Eq. (3) leads to:

$$\sigma = \pi \rho R^2 \beta_t^2 \cos\alpha \qquad [5]$$

Substituting Eq. (5) into Eq. (2) results into a squared range which is inversely related to the returned laser signal (Eq. (6)), and independent of the laser beam width (Höfle and Pfeifer, 2007).

$$P_r = \frac{P_t D_r^2 \rho}{4R^2} \eta_{sys} \eta_{atm} \cos\alpha \qquad [6]$$

Considering the assumption that the target object has Lambertian scattering properties and covers the entire hemisphere implies a solid angle of π steradian and so the effective aperture $D_r^2 = 4$ is equivalent to π. With these assumptions factored into Eq. (2), the radar range equation can be rewritten as described in Eq. (7) (Soudarissanane *et al.*, 2011):

$$P_r = \frac{P_t \cos\alpha}{R^2} \pi \rho \eta_{sys} \eta_{atm} \quad [7]$$

In terms of TLS systems, Eq. (7) can be written as:

$$P_r = \frac{K \rho \cos\alpha}{R^2} \quad [8]$$

Where the term K = $(P_t D_r^2/4)\eta_{Sys}\eta_{Atm}$ in the original radar range equation (Eq. (2)) is taken to be a constant. The power received, P_r is taken to be equivalent to the recorded laser returned intensity. The reflectance, incidence angle and range are as defined above.

Near-Distance Correction

According to Fang *et al.* (2015), for a coaxial laser scanner, the near-distance effect can be described as the ratio of the input laser signal that the detector captures between the limited range (R) and unlimited range (∞) as shown in Eq. (9).

$$\eta(R) = \frac{P(R)}{\mathrm{p}(\infty)} = 1 - exp\left\{\frac{-2r_d^2(R+d)^2}{D^2\left[\left(1-\frac{s_d}{f}\right)R+d-\frac{ds_d}{f}+s_d\right]^2}\right\} \quad [9]$$

Where r_d is the radius of the circular laser detector, d is the offset between the measured range R and the object distance from the lens plane, D is the diameter of the lens, S_d is the fixed distance of the detector from the lens and f is the focal length. All of which are parameters of the laser scanner. Combining Eq. (9) with Eq. (8) and taking into account the near-distance effect, the recorded raw intensity (I_{raw}) value can be written as:

$$I_{raw} \propto P_r = \eta(R)\frac{K\rho cos\alpha}{R^2} \quad [10]$$

Oren–Nayar Reflectance Model vis-à-vis Target Surface Roughness

The Oren–Nayar model is a Bidirectional Reflectance Distribution Function (BRDF) since it models the reflectance with regards to both the incidence and the reflection direction. The Oren–Nayar model is expressed in the following form:

$$L = \rho E_0 \cos\theta_i (A + BMax[0, \cos(\phi_r - \phi_i)] \sin\alpha \tan\omega) \quad [11.1]$$

$$A = 1.0 - 0.5 \frac{\sigma_{slope}^2}{\sigma_{slope}^2 + 0.33} \quad [11.2]$$

$$B = 0.45 \frac{\sigma_{slope}^2}{\sigma_{slope}^2 + 0.09} \quad [11.3]$$

Where L is the radiance, E_0 is the radiant flux received at normal incidence angle in radians, ρ is the material reflectivity, α is the incoming and ω the outgoing incidence angle, ϕ_r and ϕ_i are the reflected and incident viewing azimuth angle in radians and σ_{slope} as the standard deviation of the slope angle distribution in radians.

In the Oren-Nayar reflectance model, an important parameter which models the effect of a faceted surface on reflection is the standard deviation of the slope angle of facets (σ_{slope}).

According to Carrea *et al.* (2016), the model Eq. (11) can be applied in TLS systems where in terms of the configuration, the incidence and reflected rays are coincident as expressed below:

$$\phi_r - \phi_i = 0 \xrightarrow{yields} \cos(\phi_r - \phi_i) = 1 \quad [12]$$

Therefore Eq. (11) which is a BRDF can be turned into a non-BRDF where *α* the incoming incidence angle is equal to *ω* the outgoing incidence angle and then rewritten as:

$$L = \rho E_0 \cos\alpha (A + B \sin\alpha \tan\alpha) \quad [13.1]$$

$$A = 1.0 - 0.5 \frac{\sigma_{slope}^2}{\sigma_{slope}^2 + 0.33} \quad [13.2]$$

$$B = 0.45 \frac{\sigma_{slope}^2}{\sigma_{slope}^2 + 0.09} \quad [13.3]$$

Hybrid/Improved Intensity correction Model

Since Eq. (10) has K as a constant, it can be simplified and rewritten as:

$$I_{raw} = \eta(R)\frac{\rho cos\alpha}{R^2} \qquad [14]$$

The corrected intensity (I_{corr}) value can be computed as follows considering the near distance effects, material reflectivity, incidence angle and range:

$$I_{corr} = I_{raw}.\left\{\eta(R)\frac{\rho cos\alpha}{R^2}\right\} \qquad [15]$$

This intensity correction (Eq. (15)) can be used for perfect diffuse scattering surfaces. However, for surfaces with micro-facets this correction would not work well and so there is need to integrate the standard deviation of the slope angle since each facet on the surface has its own normal. Thus a hybrid intensity correction model that considers near distance effects and also integrates the Oren-Nayar model is proposed to improve the intensity correction.

$$I_{corr} = I_{raw}.\left\{\eta(R)\frac{\rho cos\alpha(A+B\sin\alpha\tan\alpha)}{R^2}\right\} \quad [16.1]$$

$$A = 1.0 - 0.5\frac{\sigma_{slope}^2}{\sigma_{slope}^2+0.33} \quad [16.2]$$

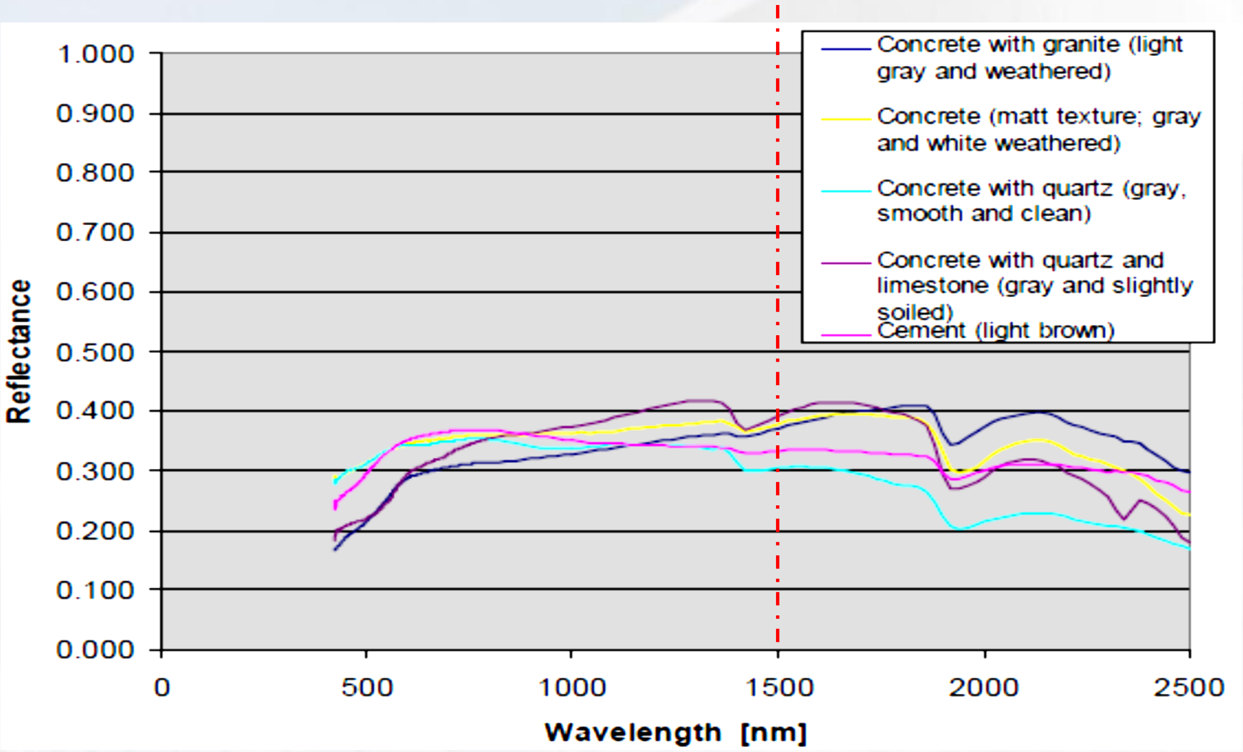
$$B = 0.45\frac{\sigma_{slope}^2}{\sigma_{slope}^2+0.09} \quad [16.3]$$

Determination of std dev of the slope angle of facets (σ_{slope})

The standard deviation of the slope angle of facets (σ_{slope}) was determined as in Carrea *et al.* (2016). An optimal σ_{slope} value was computed which would give a minimal variation of the corrected intensity by taking into consideration the different incidence angles. An optimisation function was employed in order to calculate the optimal value of σ_{slope}. The function is as written in Eq. (17) below:

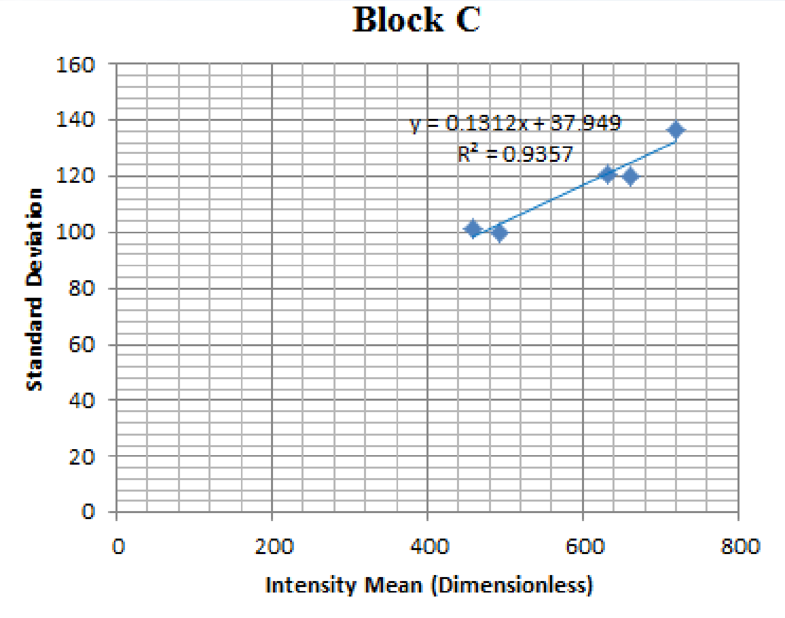
$$\min_{0\leq\sigma\leq1} f\left(\sigma_{slope}\right) = \left|\frac{1}{n}\sum_{i=1}^{n}\left(I_{corr_{10°}^{0°}}\left(\sigma_{slope}\right)\right) - \frac{1}{n}\sum_{i=1}^{n}\left(I_{corr_{45°}^{0°}}\left(\sigma_{slope}\right)\right)\right| \quad [17]$$

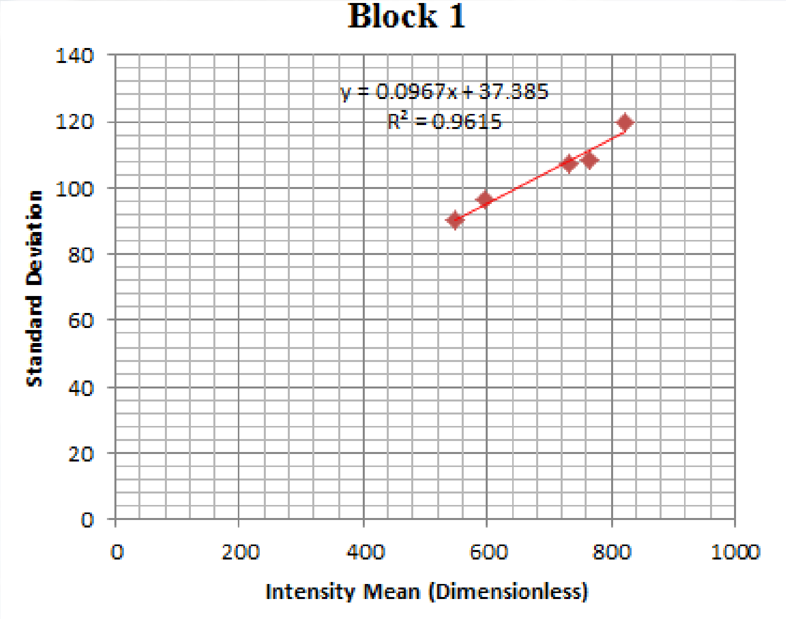
Reflectivity of various types of concrete at different wavelenghths. The HDS7000 scanner has a wavelength of 1500nm and the reflectance of concrete was taken to be in the range between 0.300 to 0.400. The concrete used in the study was gray and with some roughness

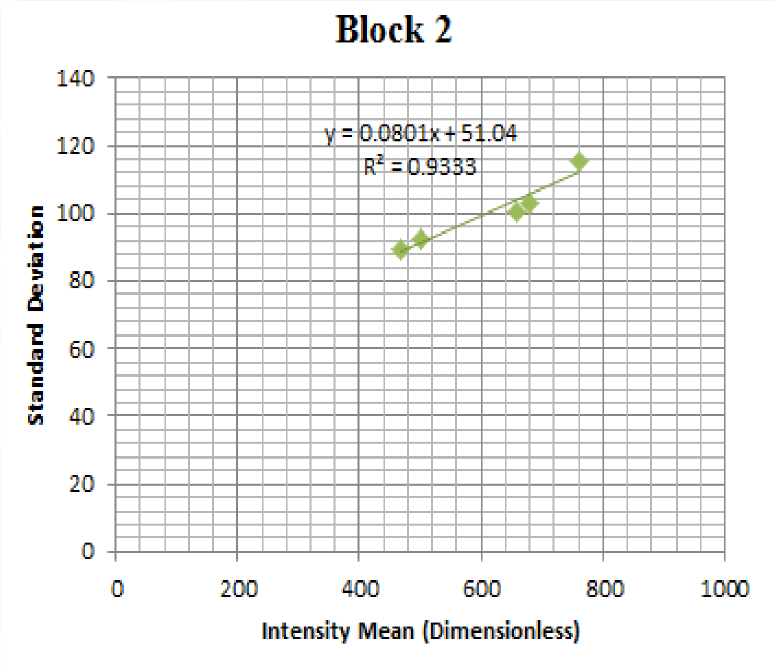


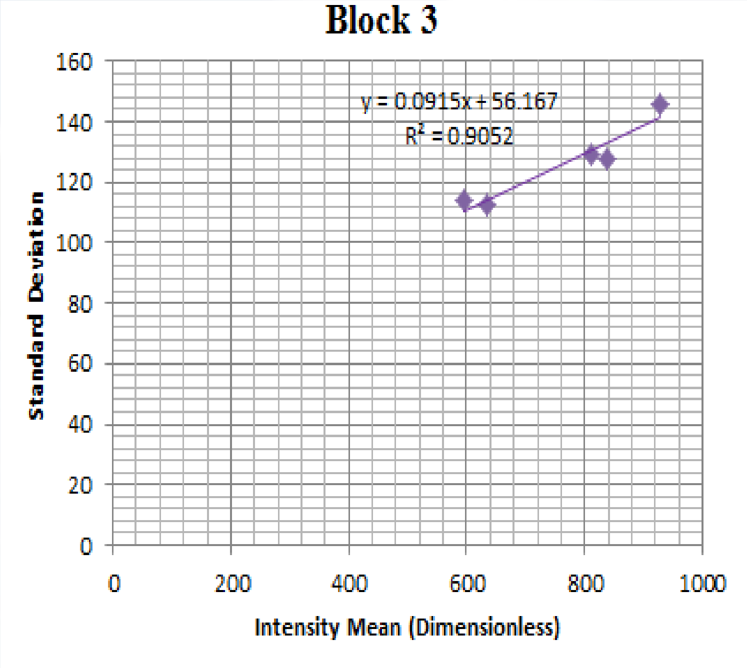
RESULTS AND ANALYSIS

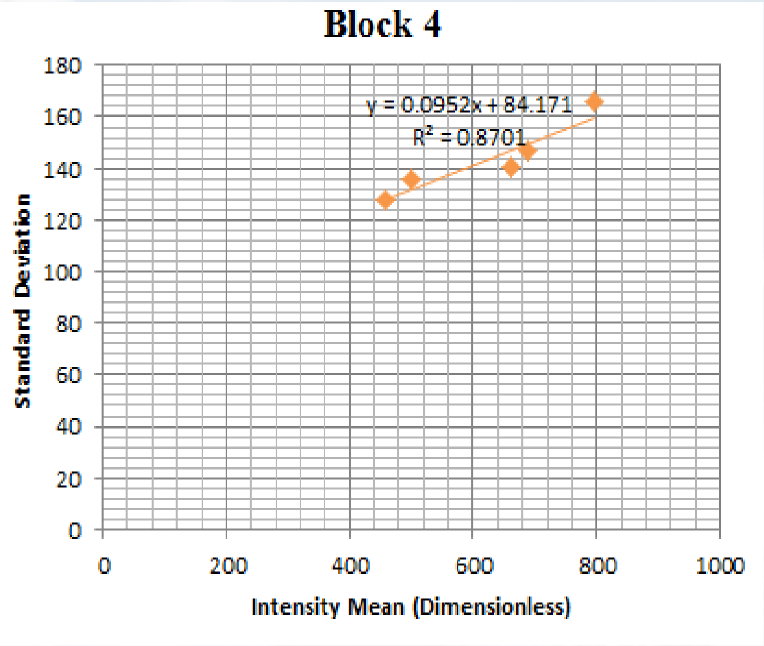
Intensity Standard Deviation





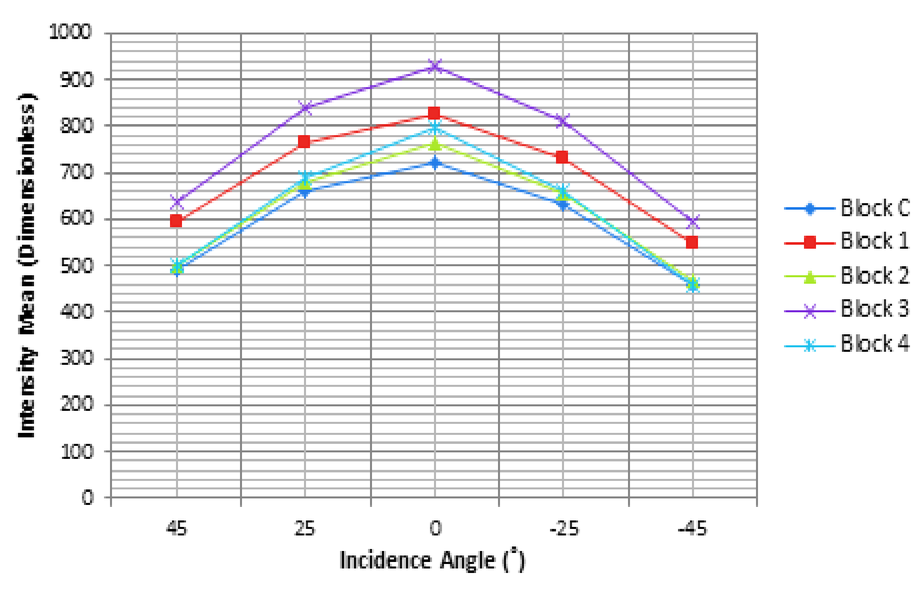

Block 2
y = 0.0801x + 51.04
R² = 0.9333
Standard Deviation
Intensity Mean (Dimensionless)
0
20
40
60
80
100
120
140
0
200
400
600
800
1000

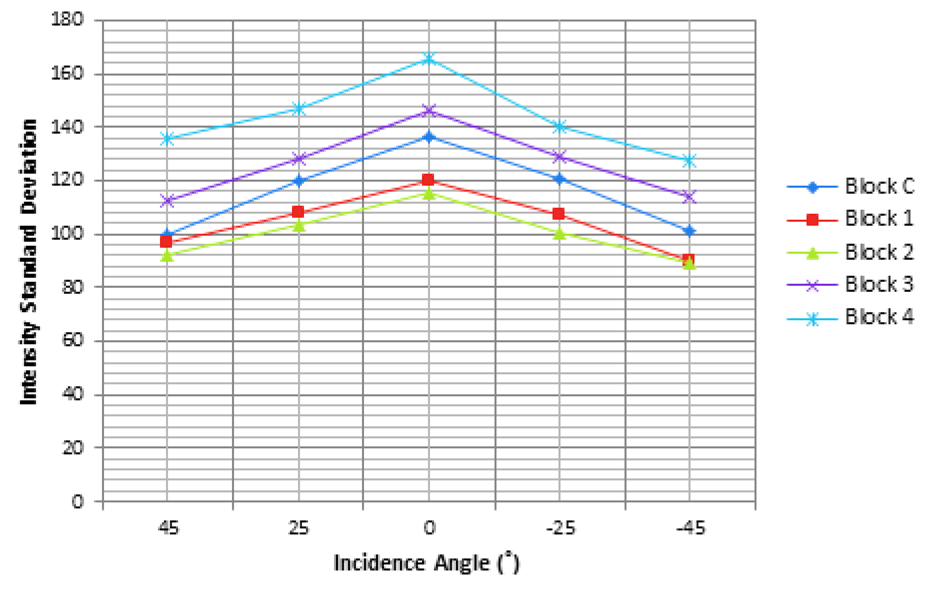

Block 3
y = 0.0915x + 56.167
R² = 0.9052
Standard Deviation
Intensity Mean (Dimensionless)
0
20
40
60
80
100
120
140
160
0
200
400
600
800
1000



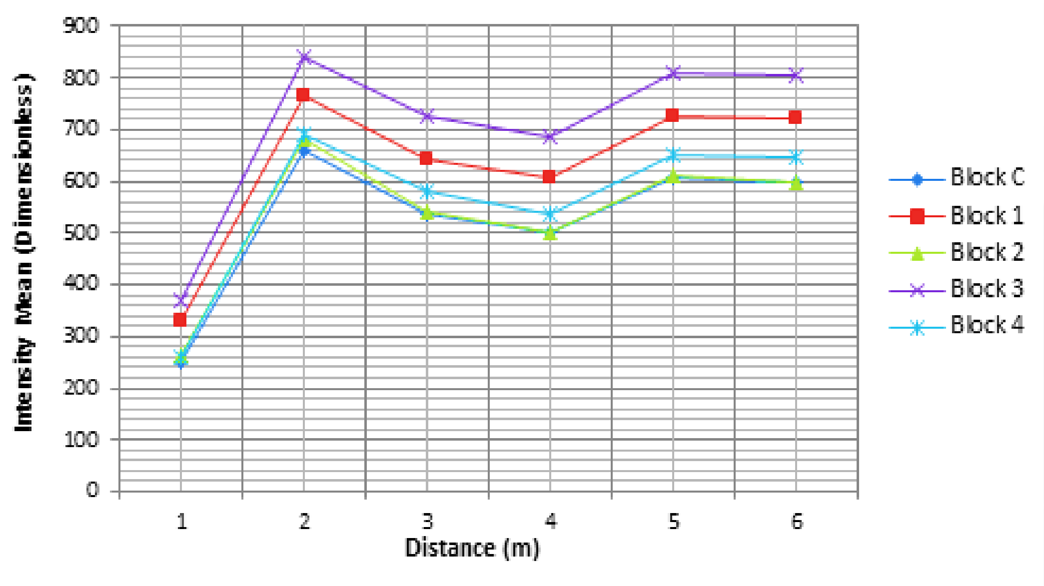
Block	Intensity Standard Deviation	
	Min	Max
Block C	100.1	136.7
Block 1	90.3	119.8
Block 2	89.2	115.5
Block 3	112.3	146.1
Block 4	127.7	165.6

Intensity and Incidence Angle (Before Correction)

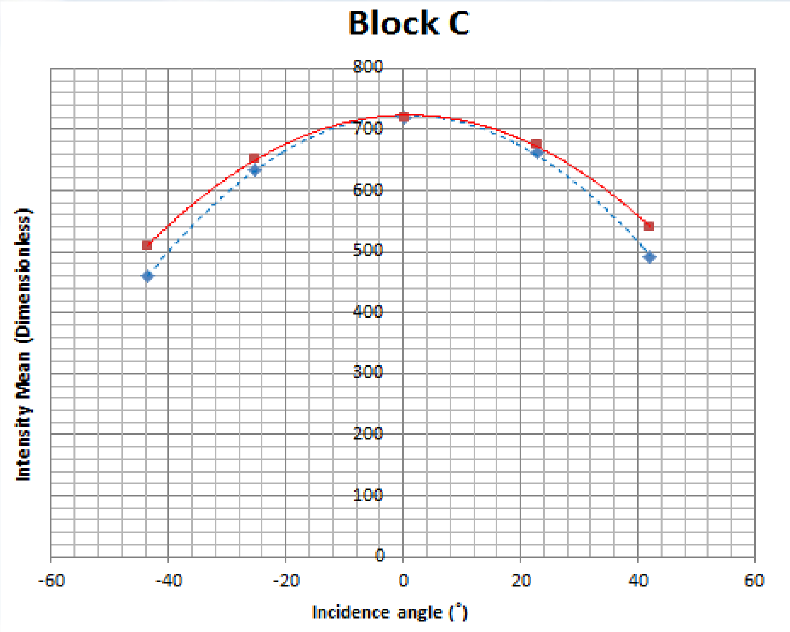


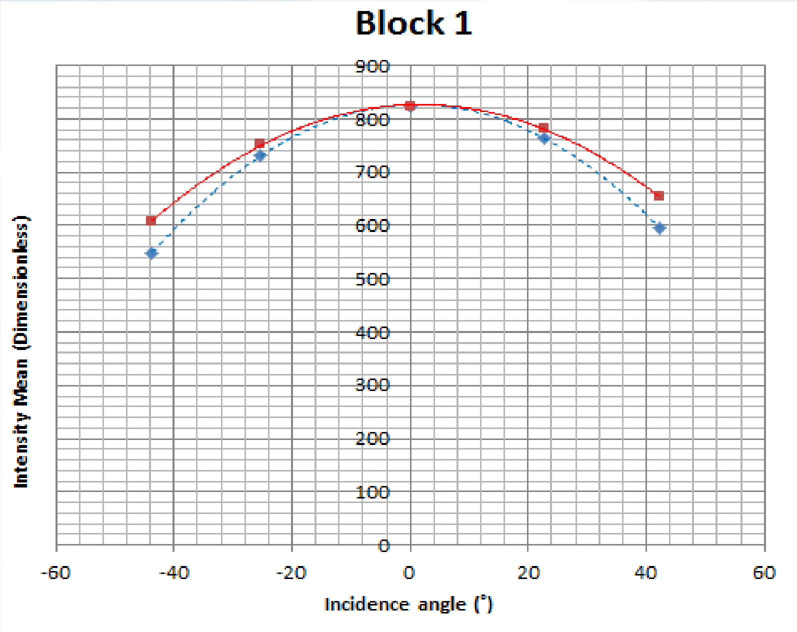


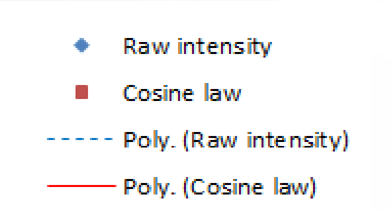
Intensity and Distance (Before Correction)



Intensity and Cosine Law Prediction vis-à-vis Incidence Angle

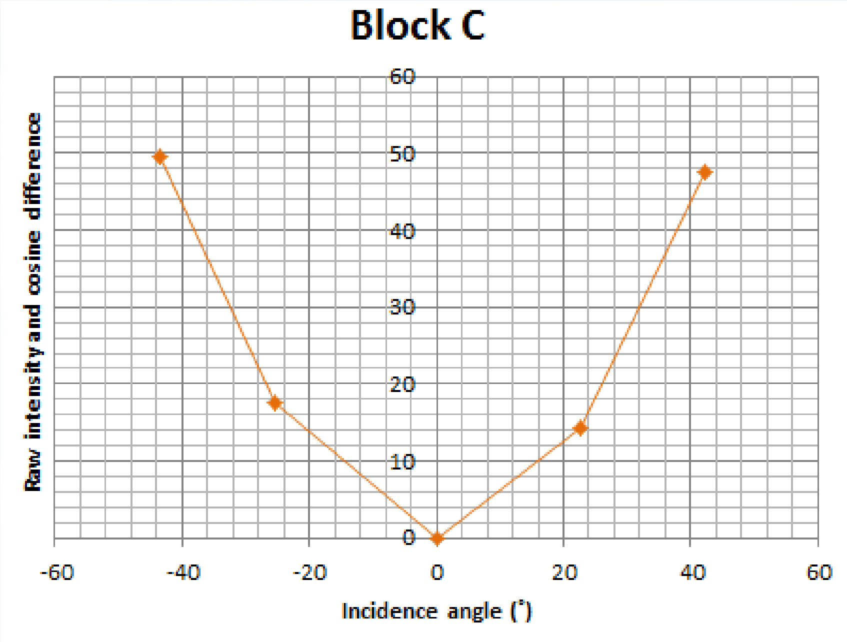


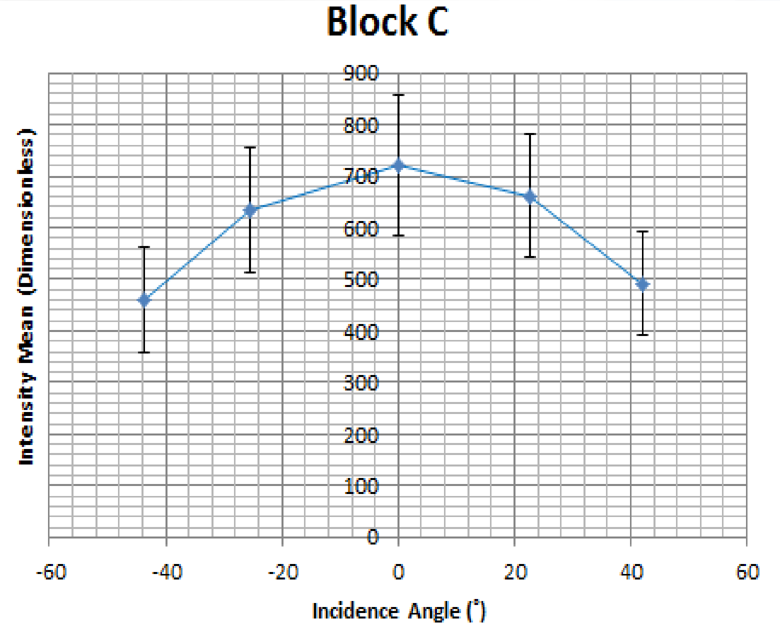




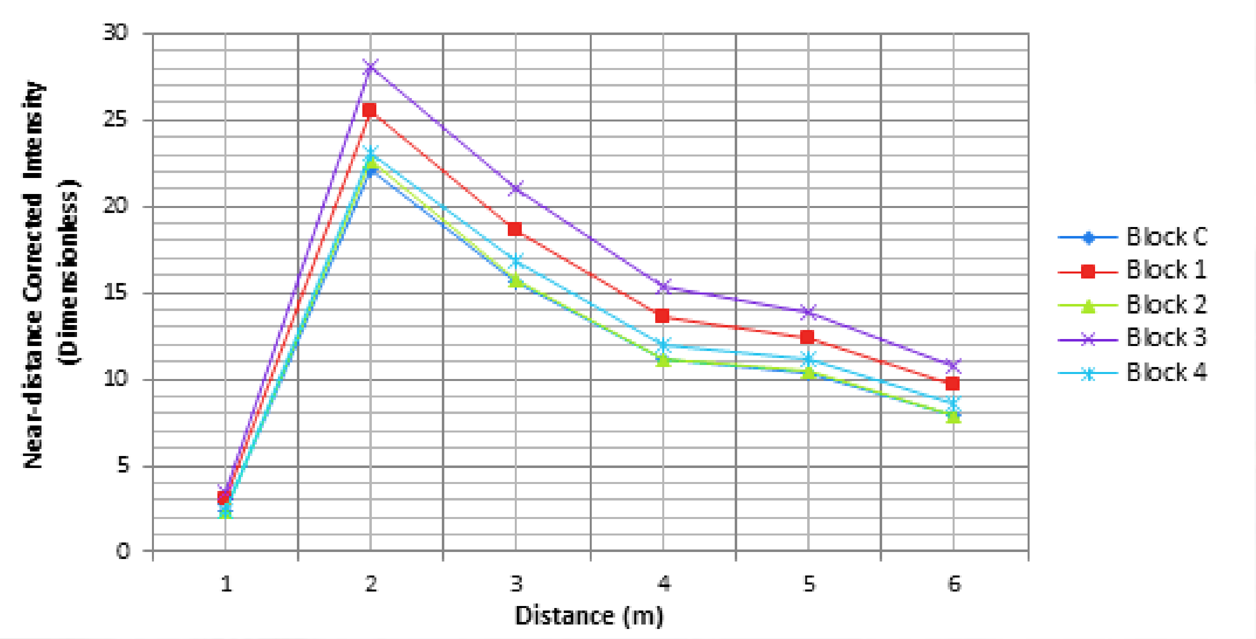
$$I_{raw} \propto P_r = K\cos\alpha \qquad [18]$$

To visualize the effect of the cosine law on the intensity values in overall scale, the average difference between the raw and cosine predicted intensity data points was plotted

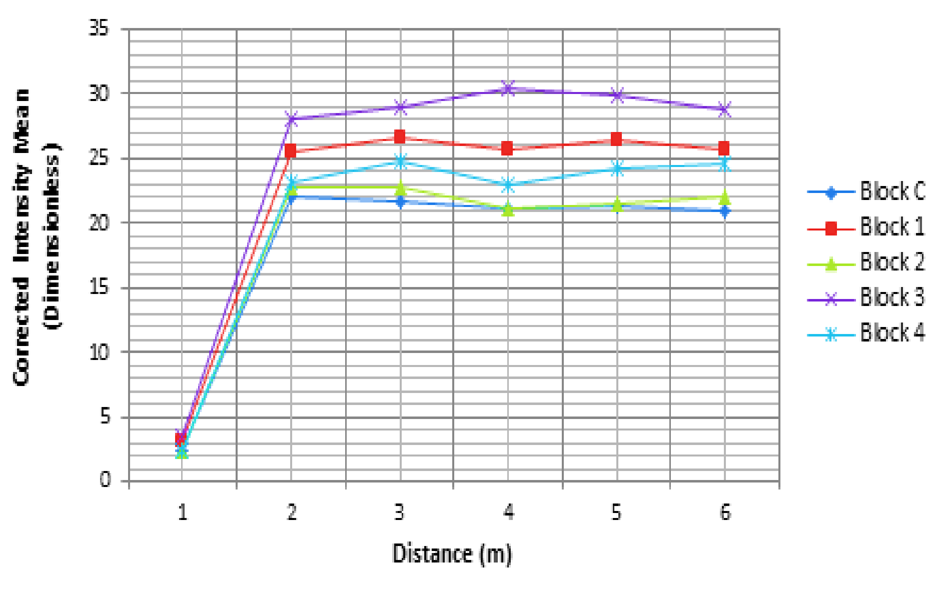


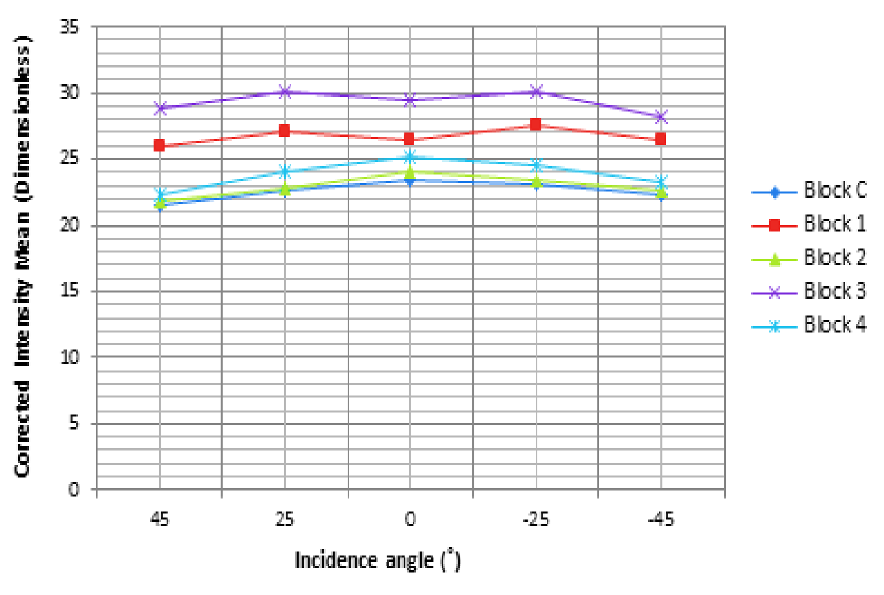


Near-Distance Intensity Correction

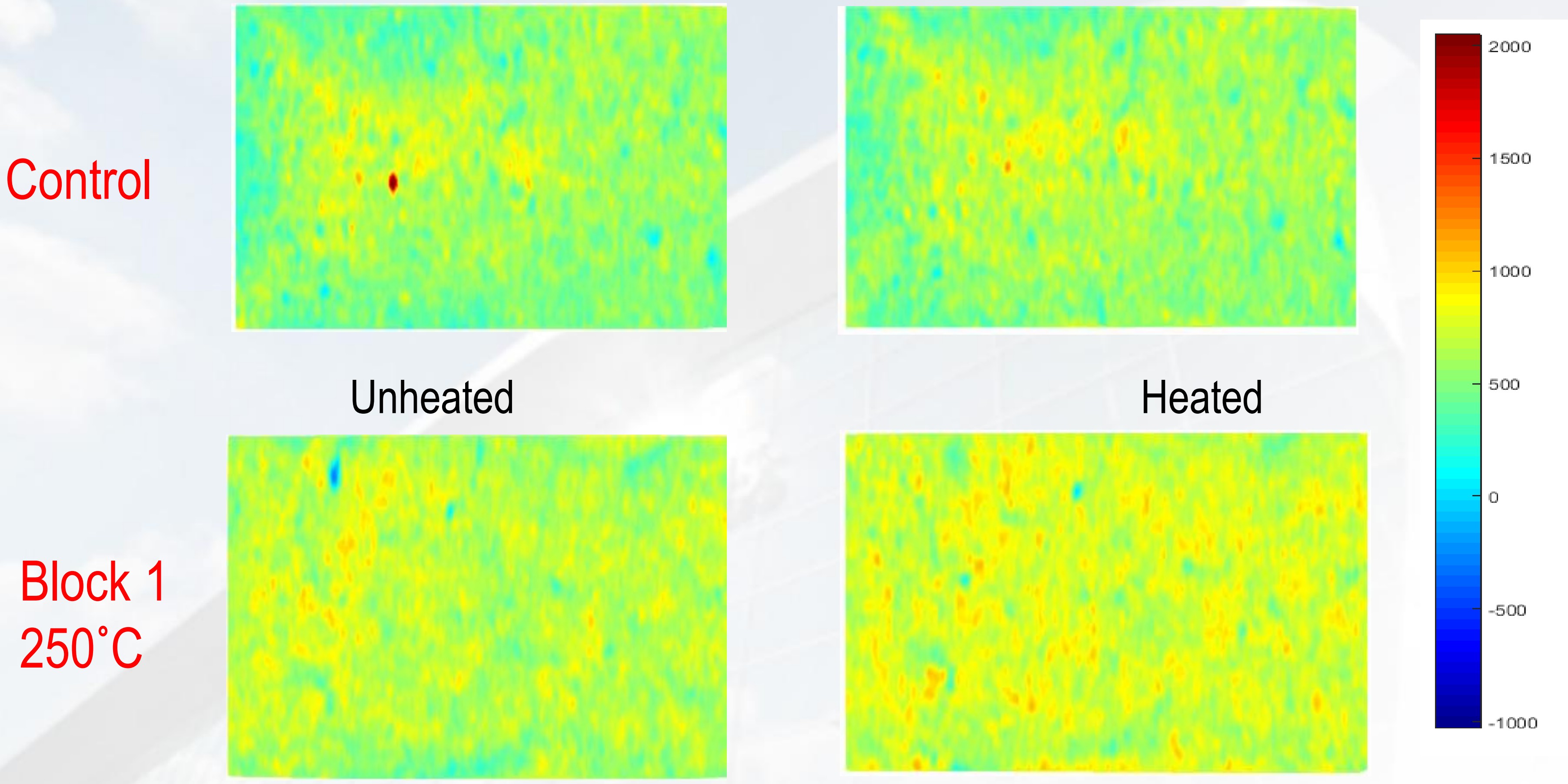


Improved Intensity Correction Method





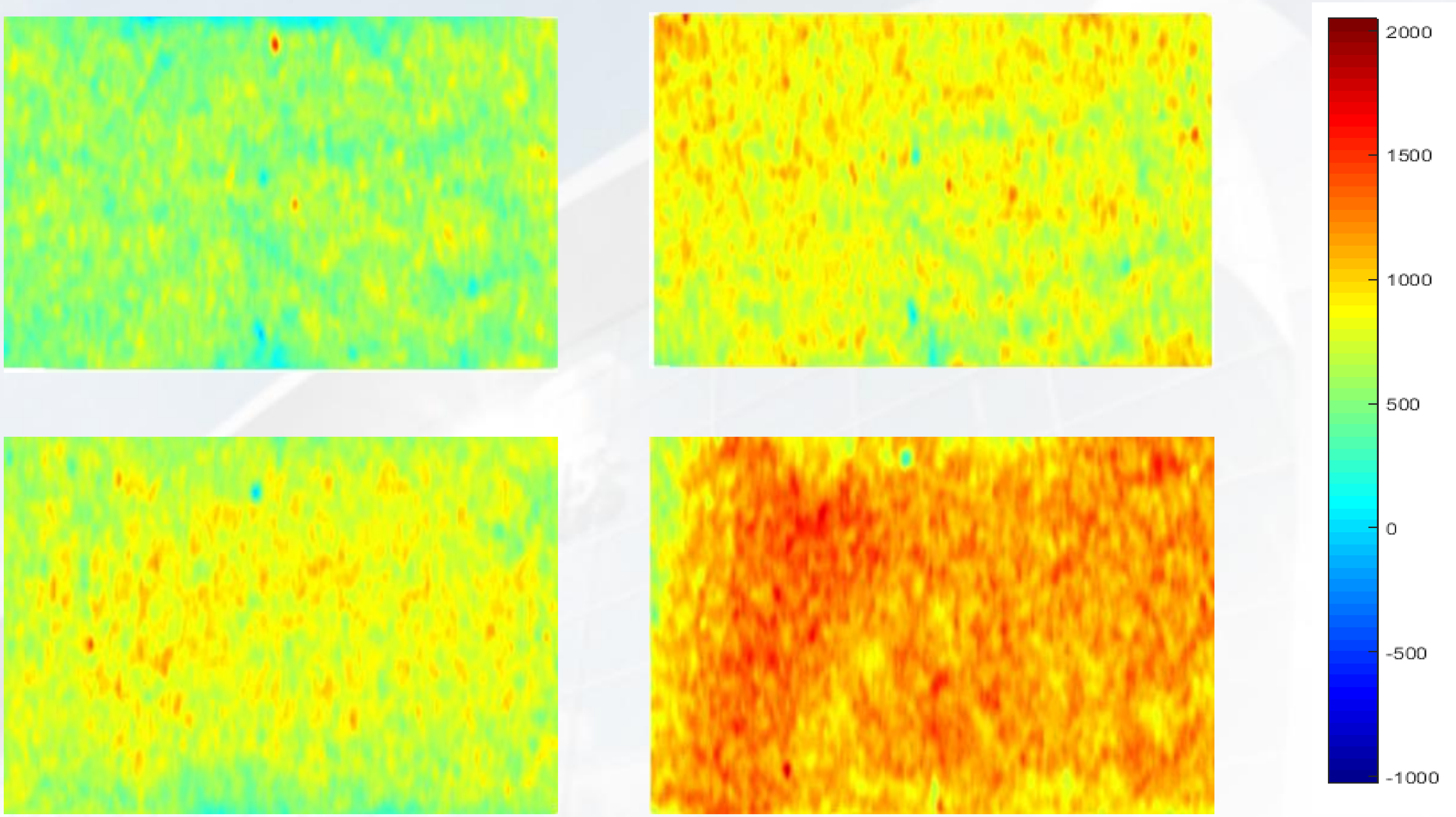
Visual Inspection of Concrete Intensity Images



Unheated **Heated**

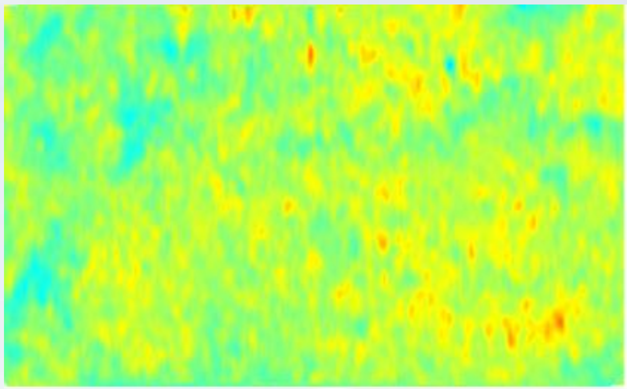
Block 2
400˚C

Block 3
700˚C

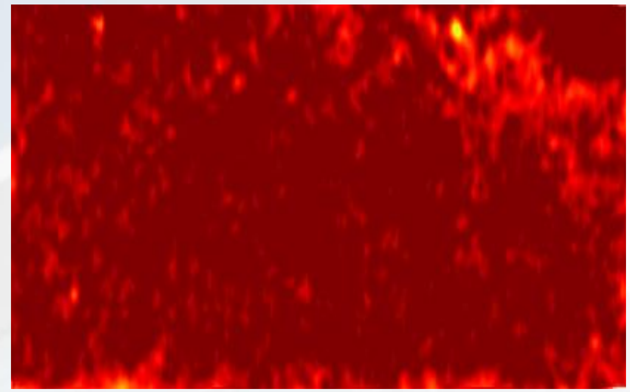


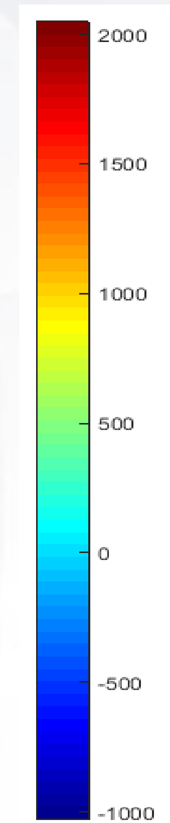
Block 4
1000˚C

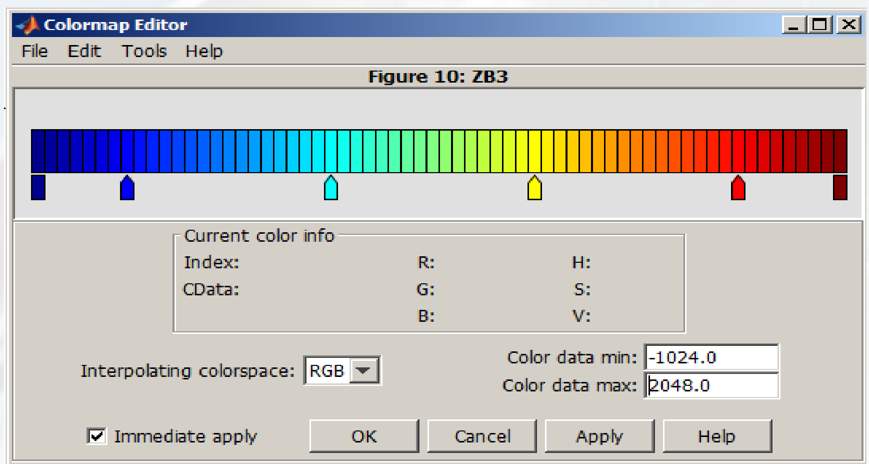
Unheated



Heated







Conclusion and Suggestions of Future Research

❑The achieved results of the intensity correction model are promising though more work still needs to be done as stated below.

❑The intensity fluctuations for any type of scanner may not be easily modelled and so there is need to know what each scanner records, whether it's the intensity or the amplitude. Instrumental effects need to be properly studied.

❑ Future research will consider:

- Using the spectrometer and the VNIR hyperspectral camera for extracting spectral charateristics of the concrete specimens.
- Test the method to correct intensity data of scanned objects with significant rough surfaces and using different scanners.
- correction for the incidence angle effects will need to be compared to that based on the linear combination of the Lambertian and Beckmann law.

Finito!

Many thanks! Any Questions?