Displacement and Illumination Levels Effect on Short-distance Measurement Errors of Using a Camera

Eduardo D. Piedad Jr. and Ricky B. Villeta

Abstract

Using a camera for measurement reading is simplified through the incorporation of computer vision application. The variations in the environment's setting, however, may constitute to the occurrence of measurement errors. A study investigated the significant effect of changing the camera-to-lens displacements and the variations of the illumination level on the short-distance measurement reading. This is performed initially by developing an actual setup calibrated though a comparison with the hypothesized values. Then, an experiment on this calibrated setup generates the measurement results of varying the displacement positions and the illumination levels. Through descriptive and comparative statistical analysis, there is evidence that the variations of the displacement alone do not significantly change the measurement results. Similarly, the variations in the illumination levels do not also constitute significant changes on the measurement results. Hence, each of the variables bears no contribution on the occurrence of the measurement error of using camera. It is further confirmed through a two way analysis of variance that there is no significant difference on the displacement positions and illumination levels, and between their interactions. These results verified that a camera can be used as a short-distance measurement tool adequately regardless on the object-to-lens displacement positions and on the illumination levels.

Keywords: measurement error, camera-to-lens displacement, illumination, computer vision, camera, descriptive and comparative analysis

1.0 Introduction

Computer vision is a field of image studies with emerging applications. Alegria and Serra (2000) use computer vision in determining the pointer's position of the analog and digital instruments. However, the use of camera is subject to certain limitations. Yuan et al (2011) formed a camera calibration method that overcomes the distortion limitations with high-accuracy calculations. Moreover, Lei et al (2008) and Tuohy et al (2010) studies present some importance of accurate measurement reading especially on moving objects. These studies only employ stationary camera and fixed illumination levels. This study, however, examines the effect of variations in camera lens-to-object displacements and illumination levels on the measurement error.

Recent studies of Heng et al (2015) and Liu et al (2015) already suggested self-calibration techniques for camera used in micro aerial vehicle and surgical visualization respectively. Another metric self-calibration and sensor modelling of Luhman (2016) were used to enhance the models and processes of camera for close-range photogrammetry. Such camera calibrations were necessary for different vision applications such as the smart security camera by Abaya (2014) and video surveillance system by Lee (2014). Hence this paper ought to validate the camera measurement reading subjected under the displacement and illumination variations which can be applied to vision-based measurement readings and similar vision applications. This study however is restricted to the stationary and short-distance camera measurement reading due to the limitation of the used camera and the setup.

Meyer and Beucher (1990), and Luccheseyz and Mitray (2001) studies both formed the morphological and the color image segmentation where the detection of markers and other image processing applications were presented. Rathi et al (2007) study tracks objects using particle filtering for geometric active contours. With the generation of various techniques and toolbox supports, computer vision simulations became more accessible. The well-known OpenCV (Intel Open Source Computer Vision Library) is a useful toolbox for computer vision practitioners (Bradski&Kaehler, 2008). Bradski and Kaehler (2008), Szeliski (2010) and Laganière (2011) books provide programming exercises and samples which the proposed working model can be acquired.

An actual experiment is performed in this study to determine whether the distance and illumination variations significantly contribute to the generated error. This is initially achieved by establishing and calibrating the proposed computer vision application by comparing the hypothesized setup with the actual experimentation setup. This working model employs Visual Studio C++ application with OpenCV library. The contour-segmented detection of these markers uses the RGB values and pre-calibrated hue saturation value (HSV).

After the calibration of the actual setup, the second part of the experimentation will verify whether the dispositions of the displacement and the illumination levels have significant effect on the measurement error. This is tested through statistical analyses such as descriptive analysis and analysis of variance (ANOVA) performed in Minitab 2017. These analyses will conform whether it is acceptable to use a camera for measurement readings by changing camera-to-lens displacements and by varying illumination levels.

2.0 Conceptual Framework

The primary goal of this study is to conduct a measurement error analysis both on the effect of the camera lens-to-object distance and on the illumination levels. This study, as shown in Figure 1, is initiated first by establishing a working system. The said setup includes the development of a measuring camera integrated by a computer vision application and placed in measured positions. Then, a hypothesized setup will be established and used as a design to the actual setup. The comparison on the hypothesized and the actual results will be verified through a statistical analysis whether the values are significantly differed. If found no evidence of significant difference, the actual setup is suggestively calibrated. The next part will be the experimentation of the two concerned variables –the lens-to-object displacement and the illumination levels.

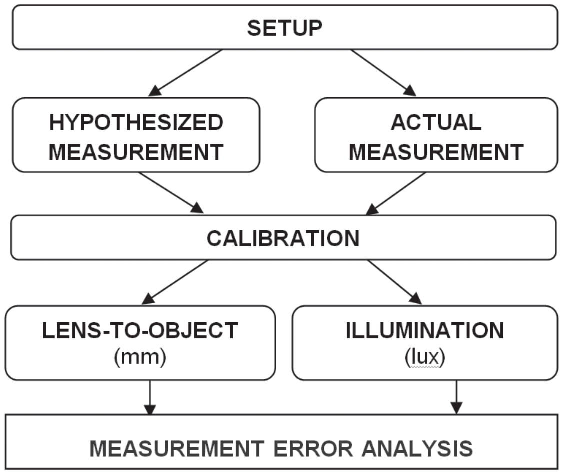


Figure 1. *Conceptual Framework*

The generated results will undergo an analysis to determine whether each or the interaction between the two variables have significance on the occurrence of measurement error on the said setup. Finally, the results of the analysis will further define whether the use of the camera with the proposed setup is acceptable to be used as a measurement tool regardless of the variations of the lens-to-object displacement positions and the different illumination levels.

3.0 Materials and Methods

A high-speed Logitech HD Pro C920 camera is used as shown in Fig 3. A working application is run in a Visual Studio C++ compiler installed with OpenCV library. This application pre-calibrates and detects a yellow-green marker with the Red-Green-Blue [RGB = (230, 245, 50)] and the HSV values [H = (25, 85), S = (53, 155), V = (118, 214)] as shown in Fig 2. Then, these values are used to the actual setup as designed in Fig 3. The application generates an excel file stored in Appendix A.

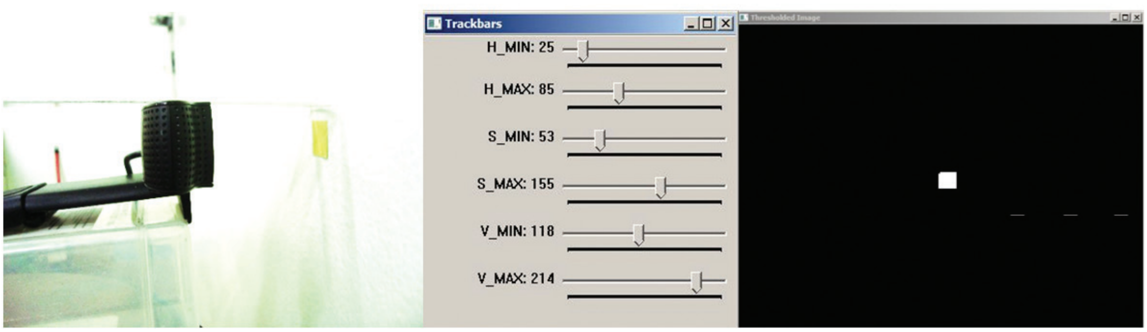


Figure 2. *Marker Detection*

The hypothesized values Yi = 150, 100, 50, 0, 50, 100, 150 (in mm) are the vertical displacements with respect to the line of sight and serves as the basis for the seven designed markers as illustrated in Figure 3. Accepting the calibration serves as the initial step to verify whether the values generated from the actual setup will not differ from the computed values. A descriptive statistical analysis will be performed in Minitab 17 software to determine whether the mean differences of the hypothesised values and the generated actual values are statistically significant. If found no evidence of significance, the actual measurement setup will be accepted.

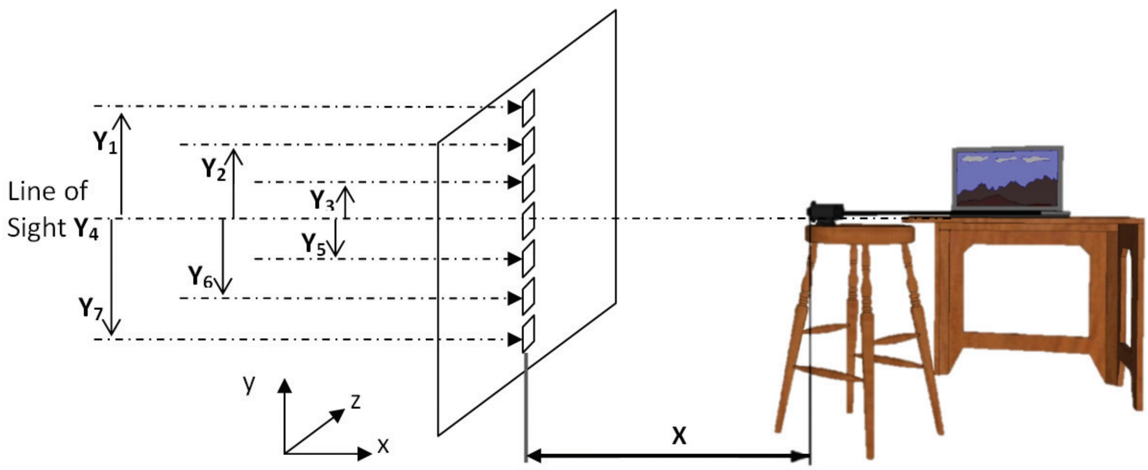


Figure 2. *Design Setup*

The displacement and illumination factors are measured simultaneously. In this simulation, lens-to-distance (X) is varied into three horizontal positions: 500, 750 and 1000 mm. The three illumination levels: (HIGH) High I > 200 lux; (MID) Moderate 200 < I < 50 lux; and (LOW) Low I < 50 lux are assumed to be even in working space. An actual simulation of proposed working model produces nine (9) observations.

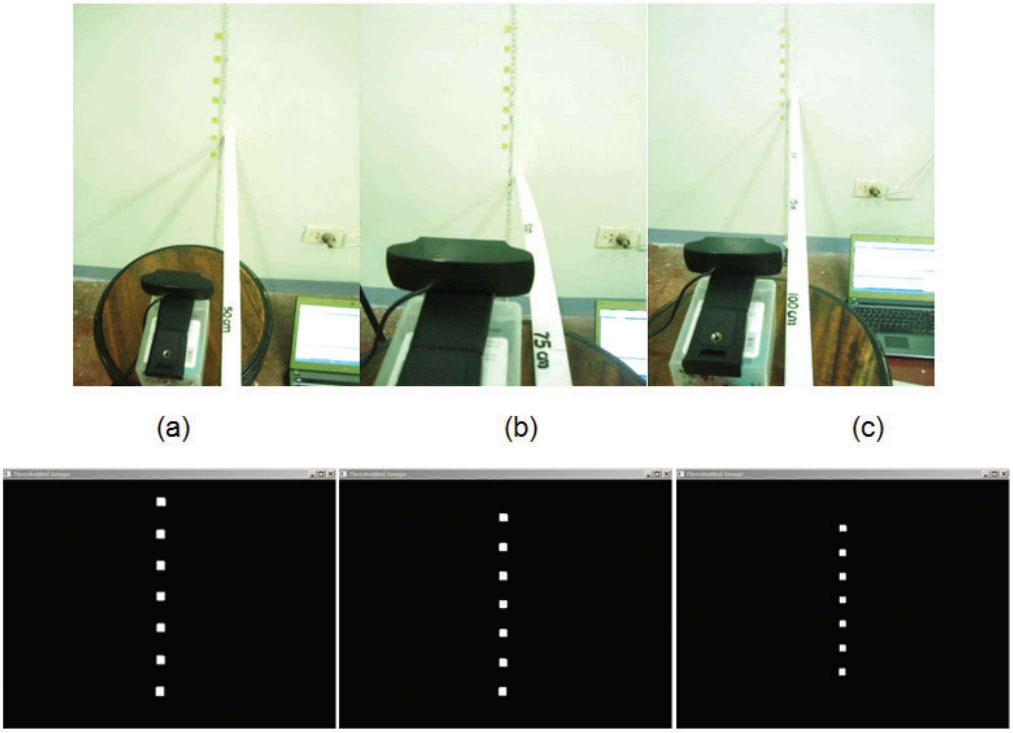


Figure 4. *(a)-(c) Design Setup of marker detections based on three distance positions with moderate illumination; (d)-(f) Computer displays of the application's detection on markers based on design setup*

Figure 4 demonstrates the actual design setup and camera detections with three different displacement positions in a moderate illumination level.

The second part of this study is to conduct an analysis on the measurement error contributed by the camera at any displacement positions and the surrounding's change in illumination levels. This is done through statistical analysis using the Minitab 2017 software. The data obtained were subjected to descriptive analysis, one-way and two-way analysis of variance, and post-hoc analysis applying Scheffe test for pair-wise differences among displacement and illumination levels. The three main effects –displacement, illumination and interactions between displacement and illumination are observed. A significance level (denoted by α) of 0.01 is observed. For p-values greater than α, there will be no significant difference between two variables. And finally, the results will define the acceptance of camera as a measurement tool whenever each or both these two variables are varied.

4.0 Results and Discussion

Before the data undergoes descriptive analysis, the generated data in Appendix A were normal when performing normality test as shown in Appendix B. Using the seven test points, the actual setup produces a mean actual value very close to the hypothesized with a small estimated difference as shown in Table 1. It can be shown from the confidence of interval (-67.8, 64.5) where zero is bounded within.

Table 1. *Two Sample T-Test and Confidence Interval (CI)*

VARIABLES	N	MEAN	StDev	SE Mean
Hypothesized	7	85.7	55.6	21.0
Actual	7	87.3	56.8	21.0
Estimate for difference			-1.6	
95% CI for difference			(-67.8, 64.5)	
		T-Value	**P-Value**	**DF**
T-Test of difference = 0 (vs not =)		-0.05	0.958	11

Hence, the actual setup functions sufficiently on this experiment and can be used for experimentation of the displacement and the illumination factors. This is further verified when the p-value is greater than α showing evidence that the actual values generated from the designed actual setup do not bear statistical significance to the hypothesized values. In addition, the T-test result shows that the generated values are adequately precise gaining acceptable errors.

With the verified actual setup, a simultaneous examination of the displacement and illumination is first performed. Table 2.1 and 2.2 show the statistical result of both the distance and illumination levels have three variations having 21 actual samples each. Accordingly, the means of both displacement and illumination levels have small differences across all the respective variations. It is suggestive that the measurement errors of the respective variations of both levels do not vary significantly.

Table 2.1. *Descriptive Statistics of Displacement Positions*

VARIABLE	N	Mean	StDev	SE Mean
500	21	87.4	54.2	11.8
750	21	87.4	54.5	11.9
1000	21	82.3	51.3	11.2

Table 2.2. *Descriptive Statistics of Illumination Levels*

VARIABLE	N	Mean	StDev	SE Mean
HIGH	21	87.4	53.9	11.8
MID	21	87.4	54.0	11.8
LOW	21	82.5	52.2	11.4

Table 3.1 and 3.2 present the analysis of variance tests for each of the displacement position variations and the illumination levels respectively. It is shown that the measurement reading differences are relatively small for the displacement and the illumination factors with 0.07 and 0.06 F values respectively. The p-value is greater than the significance level α for both variations in displacement positions and in illumination levels. It is indeed evident that varying displacement and the illumination do not contribute to the measurement error.

Table 3.1. *One-Way Analysis of Variance (ANOVA)of Displacement Positions*

SOURCE	DF	SS	MS	F	P
Factor	2	383	191	0.07	0.935
Error	60	170921	2849		
Total	62	171303			

Table 3.2. *One-Way Analysis of Variance (ANOVA) of Illumination Levels*

SOURCE	DF	SS	MS	F	P
Factor	2	328	164	0.06	0.944
Error	60	170975	2850		
Total	62	171303			

Table 4.1. *Descriptive Analysis between Displacement Positions and Illumination Levels*

FACTOR A **(DISPLACEMENT)**	FACTOR B **(ILLUMINATION)** HIGH			MID			LOW		
	MEAN	StDev	SE MEAN	MEAN	StDev	SE MEAN	MEAN	StDev	SE MEAN
500	87.5	57.2	21.6	87.3	57.2	21.6	87.3	57.2	21.6
750	87.8	57.5	21.7	87.8	57.5	21.7	87.4	57.4	21.7
1000	87.1	55.9	21.1	86.9	56.1	21.2	72.9	48.6	18.4

Table 4.2. *Two-way Analysis Variance across Displacement and Illumination Levels*

SOURCE	DF	SS	MS	F	P
DISPLACEMENT	2	383	191	0.06	0.941
ILLUMINATION	2	328	164	0.05	0.949
Interaction	4	599	150	0.05	0.996
Error	54	169994	3148		
Total	62	171303			

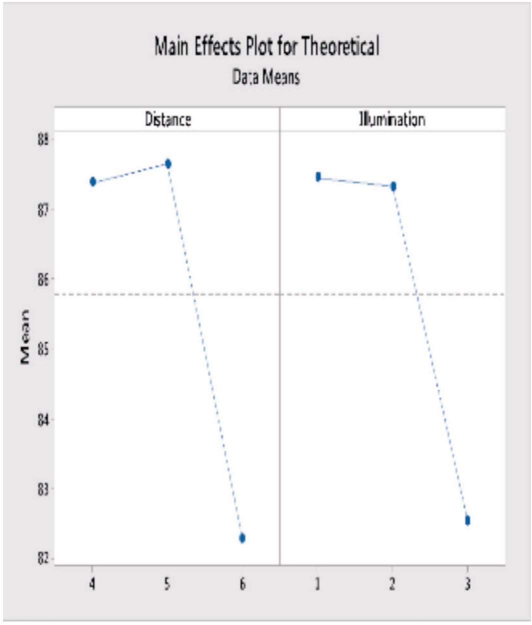


Figure 5: Main Effects for Distance and Illumination on Theoretical Measurement Errors

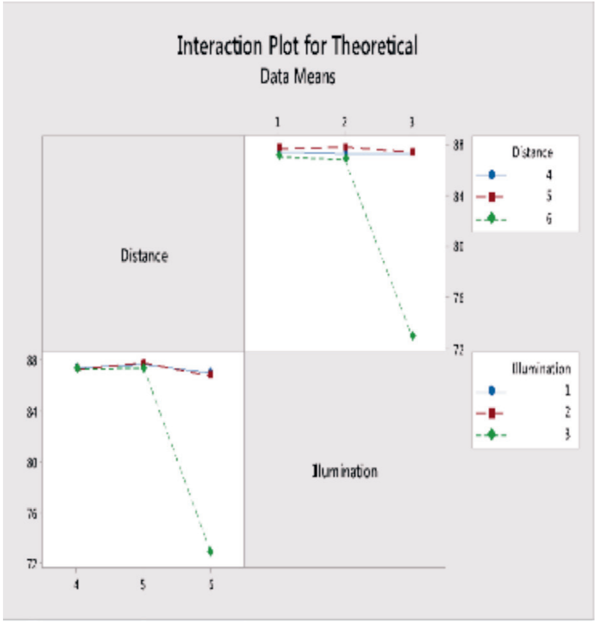


Figure 6: Interaction Effects for Distance and Illumination on Theoretical Measurement Errors

An analysis of the interaction between illumination and displacement levels in contributing measurement error is performed as shown in Table 4.1 and 4.2. It can be observed in Table 4.1 that the means of every displacement positions are approximately the same across all different illumination levels respectively. It is further verified by the latter results in Table 4.2 where p-values are much greater than α. Figs. 5 and 6 show the ANOVA plot for the results and discussion with main and interaction effects. These only show that the displacement positions in every illumination levels do not vary and the interactions between the two levels have no significant contribution to the measurement error.

5.0 Conclusion

The verification of the acceptable calibration of the camera detection and measurement was performed on the first part of the study. This part confirms that the hypothesized calculation when converted to the actual setup do not vary significantly. With this calibrated setup, the second part was then executed to investigate that the different displacement positions and the varied illuminations levels whether each or the interaction of both have significant contributions to the measurement error. It was observed that changing the displacement positions produces no significant change on the measurement reading results. Similarly, the variations in the illumination levels have no direct effect on the measurement reading. Hence, both the displacement and the illumination levels do not necessarily contribute to the measurement error of the camera. Moreover, it was also found out that the interaction between the two variables do not suggestively contribute to the measurement error. Hence, the results confirmed that the camera with the proposed design setup can be used as a measurement tool regardless of the changing lens-to-object displacements and varying illumination levels. This calibration will be used for short-distance camera measurement readings such as the augmented laparoscopic visualization of Liu et al (2015), micro aerial vehicle of Heng et al (2016), security cameras of Abaya et al (2014) and the surveillance system by Lee (2014). In addition, this paper recommends future calibration studies on moving and dynamic measurement reading.

References

Abaya, W. F., Basa, J., Sy, M., Abad, A. C., & Dadios, E. P. (2014, November). Low cost smart security camera with night vision capability using Raspberry Pi and OpenCV. In 2014 International Conference on Humanoid, Nanotechnology, Information Technology, Communication and Control, Environment and Management (HNICEM), (pp. 1-6). IEEE. Palawan, Philippines.

Alegria, E. C., & Serra, A. C. (2000).Automatic calibration of analog and digital measuring instruments using computer vision. IEEE transactions on instrumentation and measurement, 49(1), 94-99.

Bradski, G., & Kaehler, A. (2008). Learning OpenCV: Computer vision with the OpenCV library. California: Learning OpenCV: Computer vision with the OpenCV library.

Heng, L., Lee, G. H., &Pollefeys, M. (2015).Self-calibration and visual slam with a multi-camera system on a micro aerial vehicle. Autonomous Robots, 39(3), 259-277.

Laganière, R. (2011). OpenCV 2 Computer Vision Application Programming Cookbook: Over 50 recipes to master this library of programming functions for real-time computer vision. Birmingham: Packt Publishing Ltd.

Lee, K. W. (2014). Implementation of Video Surveillance System with Motion Detection based on Network Camera Facilities. The Journal of the Institute of Internet, Broadcasting and Communication, 14(1), 169-177.

Lei, Z., Xue-fei, Z., & Yin-ping, L. (2008, December). Research of the real-time detection of traffic flow based on OpenCV. In Computer Science and Software Engineering, 2008 International Conference on Computer Science and Software Engineering (Vol. 2, pp. 870-873). IEEE.Wuhan, China.

Liu, X., Su, H., Kang, S., Kane, T. D., &Shekhar, R. (2015, March). Application of single-image camera calibration for ultrasound augmented laparoscopic visualization. In SPIE Medical Imaging (pp. 94151T-94151T).International Society for Optics and Photonics.

Luccheseyz, L., &Mitray, S. K. (2001). Color image segmentation: A state-of-the-art survey. Proceedings of the Indian National Science Academy (INSA-A), 67(2), 207-221.

Luhmann, T., Fraser, C., & Maas, H. G. (2016).Sensor modelling and camera calibration for close-range photogrammetry. ISPRS Journal of Photogrammetry and Remote Sensing, 115, 37-46.

Meyer, F., &Beucher, S. (1990).Morphological segmentation. Journal of visual communication and image representation, 1(1), 21-46.Fontainebleau, France.

Rathi, Y., Vaswani, N., Tannenbaum, A., &Yezzi, A. (2007). Tracking deforming objects using particle filtering for geometric active contours. IEEE transactions on pattern analysis and machine intelligence, 29(8), 1470-1475.

Szeliski, R. (2010). Computer vision: algorithms and applications. New York: Springer Science & Business Media.

Tuohy, S., O'Cualain, D., Jones, E., &Glavin, M. (2010, June). Distance determination for an automobile environment using inverse perspective mapping in OpenCV. In Proc. Irish Signals and Systems Conference (Vol. 2010).

Xin, Y., Ruishuang, Z., & Li, S. (2011). A calibration method based on OpenCV. 3rd International Workshop on Intelligent Systems and Applications, (pp. 1-4). Wuhan, China.

Appendix A

Table I. *Hypothesized and Actual Values*

Hypothesized	Actual
150.0000	156.0029
100.0000	102.3902
50.0000	52.8868
0.0000	0.2088
50.0000	49.0877
100.0000	100.0345
150.0000	150.7062

Table II. *Raw Data of 500 mm*

TEST POINTS (mm)	FACTORS		
	HIGH	MID	LOW
150	158.2748449	158.2748449	158.2748449
100	103.0791871	103.0791871	103.0791871
50	52.69379217	52.69379217	52.69379217
0	0.835000776	0.835000776	0.835000776
50	47.64341358	47.64341358	47.64341358
100	99.60716816	98.74451298	98.74451298
150	150.0671495	150.0671495	150.0671495

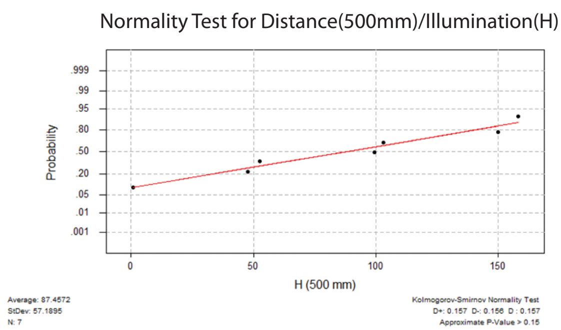
Table III. *Raw Data of 750 mm*

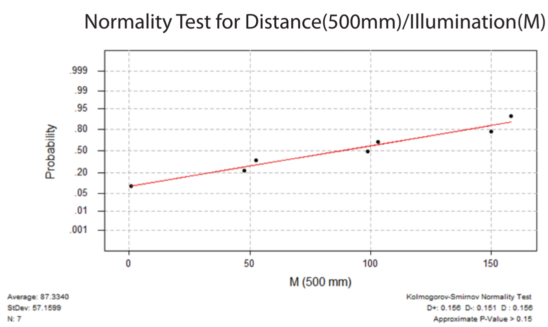
TEST POINTS (mm)	FACTORS		
	HIGH	MID	LOW
150	157.2242259	158.5243919	157.2242259
100	105.6837723	103.1378669	103.1378669
50	52.5859184	52.5859184	52.5859184
0	0	0	0
50	47.56110127	48.81877248	47.56110127
100	100.5942922	100.5942922	100.5942922
150	150.713394	150.713394	150.713394

Table IV. *Raw Data of 1000 mm*

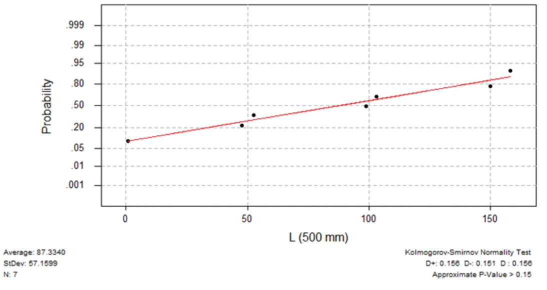
TEST POINTS (mm)	FACTORS		
	HIGH	MID	LOW
150	152.8335632	152.8335632	152.8335632
100	100.3346721	100.3346721	100.3346721
50	53.380616	53.380616	53.380616
0	0	0	0
50	51.71603182	50.04170838	51.71603182
100	100.3346721	100.3346721	100.3346721
150	151.1249897	151.1249897	151.1249897

Appendix B

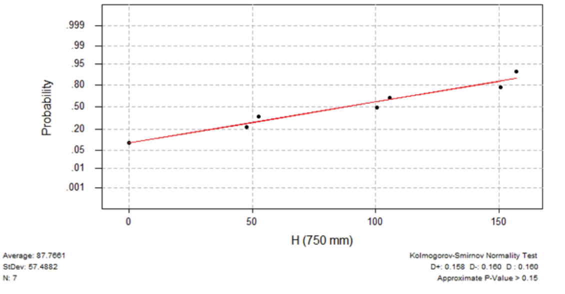




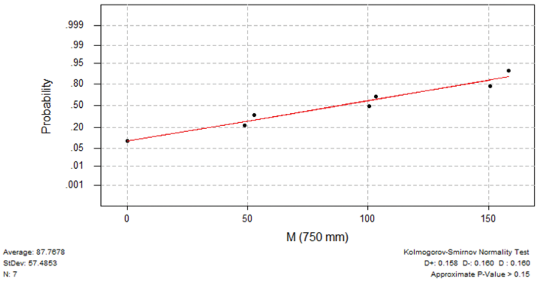
Normality Test for Distance(500mm)/Illumination(L)



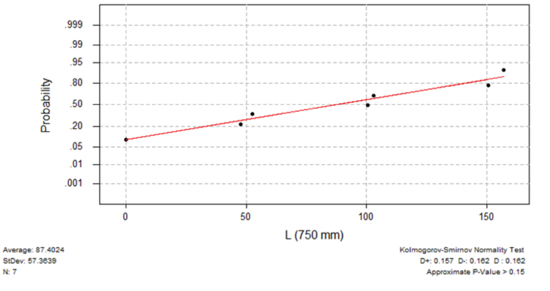
Normality Test for Distance(750mm)/Illumination(H)



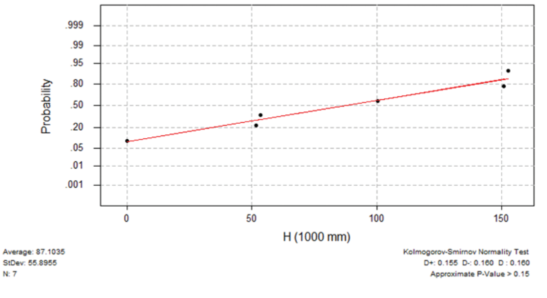
Normality Test for Distance(750mm)/Illumination(M)



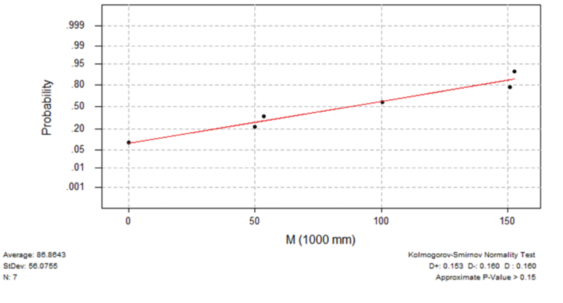
Normality Test for Distance(750mm)/Illumination(L)



Normality Test for Distance(1000mm)/Illumination(H)



Normality Test for Distance(1000mm)/Illumination(M)



Normality Test for Distance(1000mm)/Illumination(L)