Glascene – On and Beyond

2019 Group 11-07

Cheng Zihao (4S304, Leader)
Miao Rundong (4S221)

Mentor: Mrs. Rachel Chan

Hwa Chong Institution (High School)

Abstract

The project team discovered that frostiness of the projection screen seems to contradict with transparency of the glass, and decided to use Glascene， a type of glass specially designed as a transparent projection screen, and propose a solution design that combines transparency and projection capabilities. To better illustrate characteristics and potential of Glascene, the project team used it in the solution design: an interactive exhibition board, which enables viewers to select and virtually try on different types and sizes of school uniforms. Through 4 sets of quantitative analysis, the project team found that using the low-transparency Glascene, highest brightness of the projector lamp in the darkest possible environment would achieve best projection quality. The team adjusted the solution design according to these findings and came up with the final product – prototype 2.2, which is a user interface projected on the Glascene screen. The interface could be controlled by viewers simply tapping the screen, various types and sizes of Hwa Chong 100 uniforms will superimpose to the viewers' bodies when they stand behind the projection screen. Possible applications of this solution design include building glass curtain billboards, office projection screens, car window user interfaces and so much more.

1)Introduction

Transparent glass is widely used in windows (Fig 1.1), computer screens, TV screens, phone screens and glass curtain walls (Fig 1.2). Transparent glass allows most light to pass through without forming images.

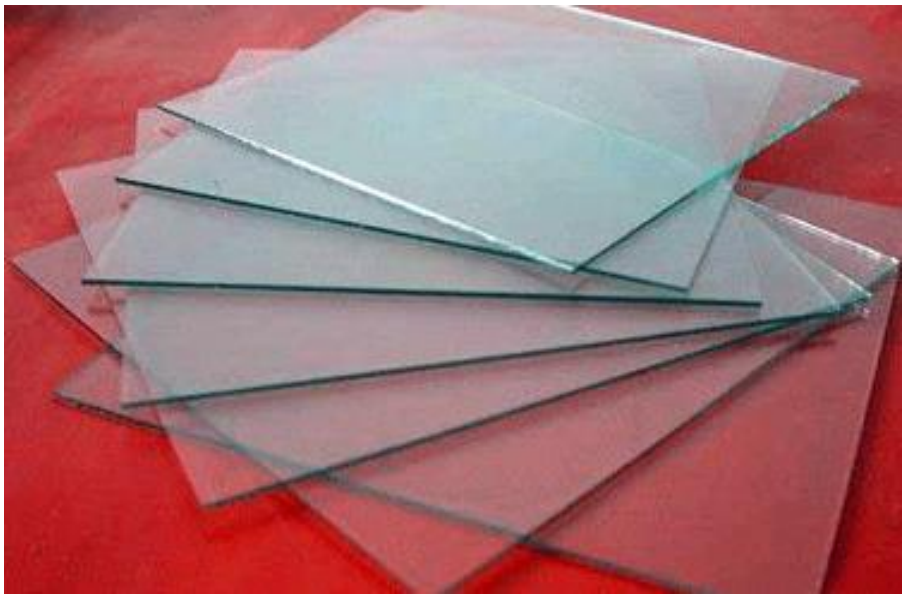


Fig 1.1 Window glass

Fig 1.2 Hong Kong city, buildings in the picture adopt glass curtain walls

Frosted glass is used as projection screens (Fig 1.3) along with non-transparent, pure white plastic and fiber. These materials block most light, and form images on the screen. These materials compromise in transparency to ensure projection quality.

Fig 1.3 Frosted glass on a projection screen

Glascene™ is a new glass type from AGC Inc, the largest glass manufacturer in the world. It is designed as a **transparent projection screen** (Fig 1.4). It is highly transparent but captures good images, bringing more possibilities to projection screens. When the projector is on, it acts as a projection screen; when the projector is off, Glascene looks highly similar to a normal glass, and people could see clearly beyond the glass. On and beyond, this is where the project title came from. Glascene could act as building windows (Fig 1.4), shop billboards (Fig 1.5), car windows (Fig 1.6), and so on, while being harmonious in style with other normal glasses.

Fig 1.4 Illustration of Glascene as building windows, adapted from AGC Inc.

Fig 1.5 Illustration of Glascene as billboards, adapted from AGC Inc.

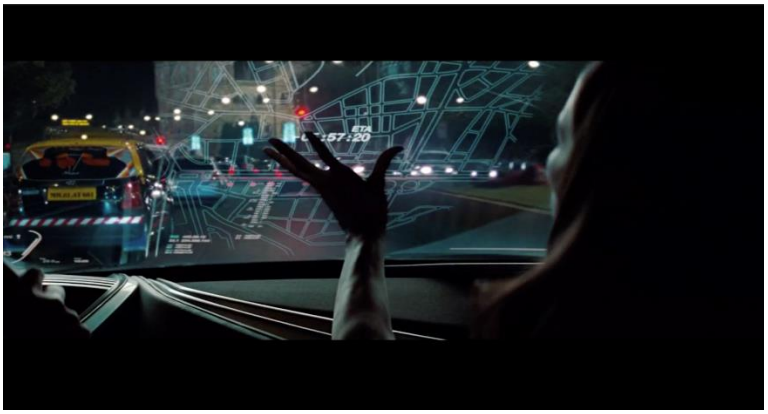


Fig 1.6 Illustration of Glascene as car windows, from *Mission Impossible: Ghost Protocol*

The project team discovered that frostiness of the projection screen seems to contradict with transparency of the glass, and decided to use Glascene samples provided to propose a solution that combines transparency and projection capabilities.

This project aims to study the mechanism, characteristics and the working condition of Glascene, in order to use Glascene as an interactive exhibition board to show the different school uniforms of Hwa Chong and allow visitors to virtually try them on, to celebrate the 100th Anniversary of Hwa Chong.

2)Objectives

An exhibition board that allows visitors to select, scroll and zoom various HC uniform and superimpose on their bodies when they stand behind the glass.

- To obtain optimum position of the projector for best projection quality.
- To make an interactive user interface.
- To integrate infra-red sensors with the projector for interaction on the interface.

3)Literature Review

3.1 Concept of contrast ratio

The paper “Influences of blackboard on teacher's and students' vision and on projection effects in multi-media classroom” revealed the relationship between sharpness of image projected and the colour of projection screen. In the paper, the two types of “project screens” are blackboard and whiteboard commonly used in schools. They use “contrast ratio” to quantify the sharpness of image projected to the screen.

The contrast ratio is defined as the ratio of the luminance of the brightest color (white) to that of the darkest color (black) that the system is capable of producing. It simply means the difference of brightness between black and white. High contrast ratio leads to the high sharpness of screen, for the great difference between darkness and brightness makes us easier to recognise every detail of image on the screen. What’s more, the great difference between darkness and brightness enables much wider range for a display to express the colour. As a result, the black part will be blacker, and the

green part will be greener. Without high contrast ratio, the image on the screen will become blurry and the colour will be much dimmer. Fig 3.1 shows the difference between high and low contrast ratio.

Fig 3.1 High (left) and low (right) contrast ratio

The contrast ratio can be mathematically defined as below:

$$C_R = \frac{\overline{E_W}}{\overline{E_B}}$$

where C_R is the contrast ratio, $\overline{E_W}$ is the average illuminance of "white" on the screen, and $\overline{E_B}$ is the average illuminance of "black" on the screen.

Although this paper uses blackboard and whiteboard as projection screen, not investigating the glass as projection screen, the idea of using contrast ratio to compare the sharpness of image on the screen is inspiring.

3.2 Literature review on "Large-area smart glass and integrated photovoltaics"

The research showed that several companies throughout the world were developing the concept of a switchable glazing for building and vehicle. Conventional glazing only offers fixed transmittance and control of energy passing through it. Photovoltaics can be integrated as power sources for smart windows. In this way a switchable

window could be a completely stand-alone smart system. This study covers selected switching technologies including electrochromism, suspended particles, and encapsulated liquid crystals.

On the other hand, a fixed glazing glass is used, which has projection purposes, just like those glasses mentioned in the study. With the aid of new technologies, the glass is more affordable, easier to operate and maintain.

3.3 Literature review on “Invited Paper: New “Glass Signage” Manufacturing, “Glass Direct Bonded LCD” and “Transparent Glass Screen””

Glass Direct Bonded LCD is a glass bonded with LCD that gives out light directly, without a projector, just like a TV. LCD technology is costly, and the interactive purposes will add a considerable thickness to the glass.

The Transparent Glass Screen the report talked about involves extensive coding to integrate GUI with infrared sensor.

A more affordable and time-saving approach was taken that involved integration of the interface and the infrared sensor with the projector. Also compared to the LCD touch screen, Glascene can be made highly transparent and thin, giving a great sense of future.

4)Solution design

4.1 Measurement

4.1.1 Measurement of Contrast ratio

Since contrast ratio is the ratio of illuminance of “white” to illuminance of “black” in the image, a rectangular “white” image, with RGB value of (255,255,255) and “black” image, with RGB value of (0,0,0), were projected to the screen, as shown in Fig 4.1.1. Set-up for the illuminance meter is shown in Fig 4.1.2 and 4.1.3. The illuminance meter recorded the variation of illuminance of the image for 20 seconds, with 5Hz of frequency of measurement taking.

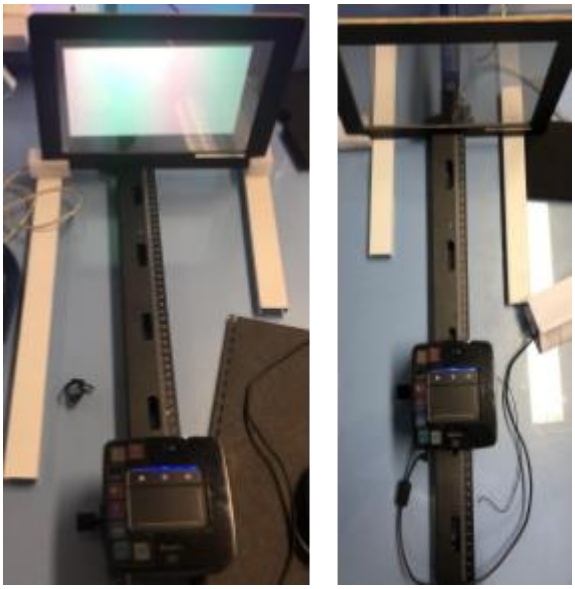


Fig 4.1.1 Actual set-up for measurement

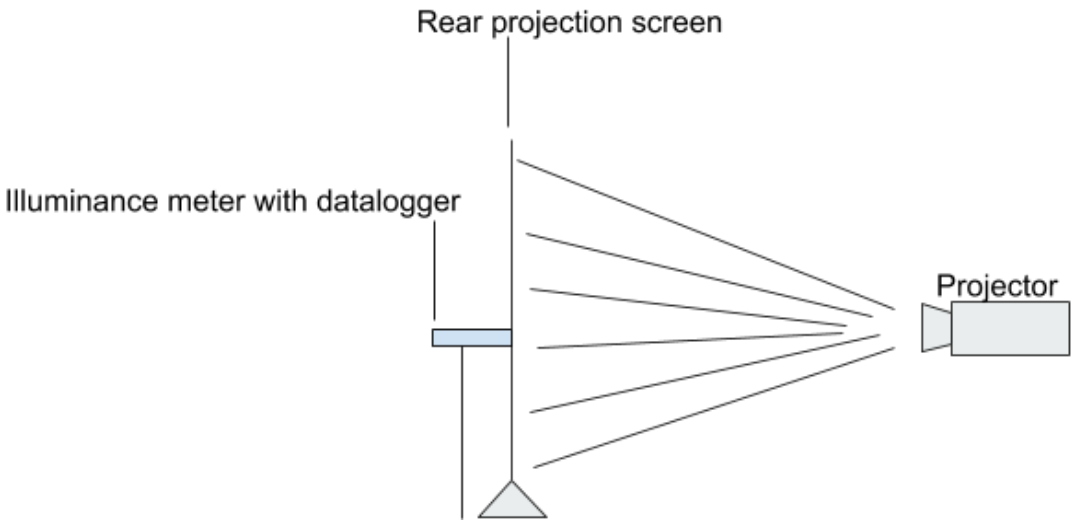


Fig 4.1.2 Experimental set-up for measuring contrast ratio

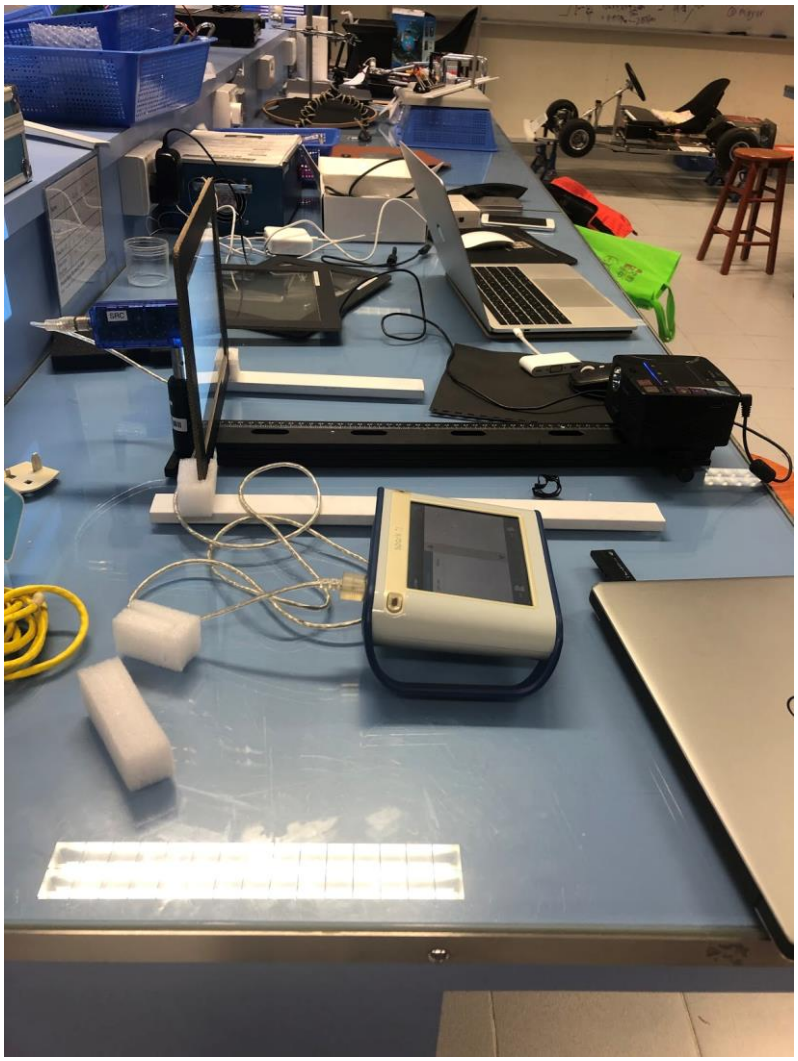


Fig 4.3 Actual set-up

4.1.2 Measurement of brightness of projector lamp

Brightness of projector lamp was varied in the settings in the projector system. Before each experiment which took brightness of projector lamp, set of the illuminance meter as shown in Fig. 4.2

Fig 4.2 Experimental set-up for measuring brightness of projector lamp

4.1.3 Measurement of surrounding light intensity

Surrounding light intensity is varied by switching on and off the 5 sets of lights in the laboratory. To measure the surrounding light intensity, another illuminance meter is added. The set-up is shown in Fig 4.3

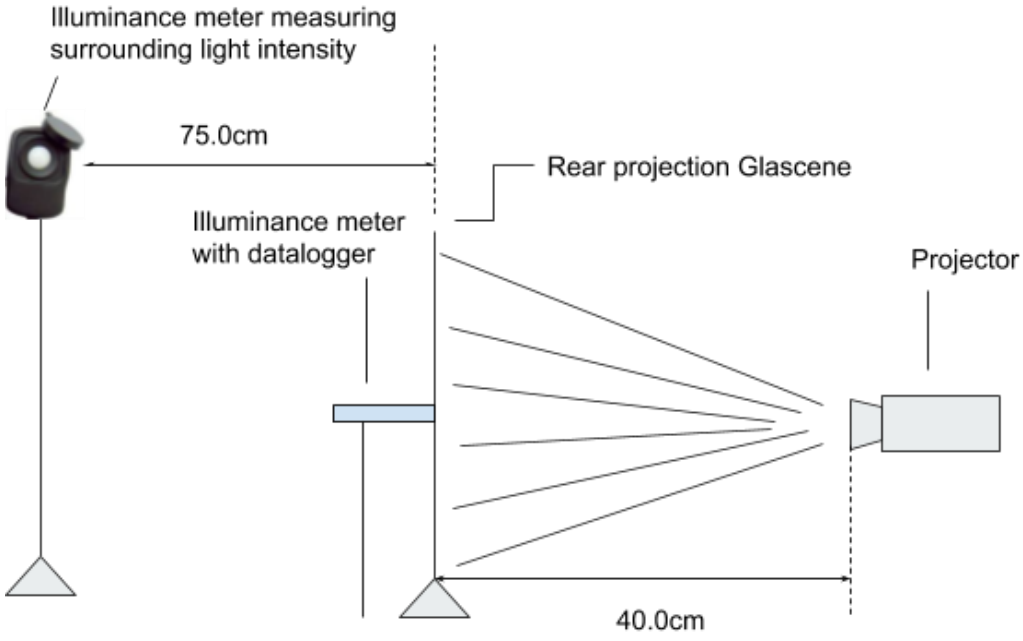


Fig. 4.3 Experimental set-up for measuring surrounding light intensity

4.1.4 Measurement of distance from projector to screen

In the experiment, the projector was set on a ruler-like and adjustable base with graduation on it, shown in Fig 4.4. The projector can slide on the base

and hence, easily being adjusted.

Fig. 4.4 Actual set-up and the graduations on the base

4.2 Interface making

The exhibition tool needed to be interactive. PowerPoint was used to develop an interface, with its powerful function of hyperlink.

5) Results & Discussion

5.1 Internal factors affecting projection quality

5.1.1 Transparency

Two types of transparency are provided. For each transparency, contrast ratio is measured, with the distance from the projector to the screen fixed at 40.0cm, and brightness of projection lamp fixed at Level 8 (in the settings). The results are shown in Annex 1.

The average contrast ratio for high transparency screen was 13.683:1, and the average contrast ratio for low transparency screen was 13.761:1.

It can be seen that lower transparency led to higher contrast ratio, making better projection quality. It is better to choose the low-transparency Glascene in practice.

5.1.2 Brightness of projector lamp

For each of the 4 different levels of brightness emitted, contrast ratio is measured, with the distance from the projector to the screen fixed at 40.0cm, using the same piece of low-transparency Glascene. The results are shown in

Annex 2 and Fig. 5.1

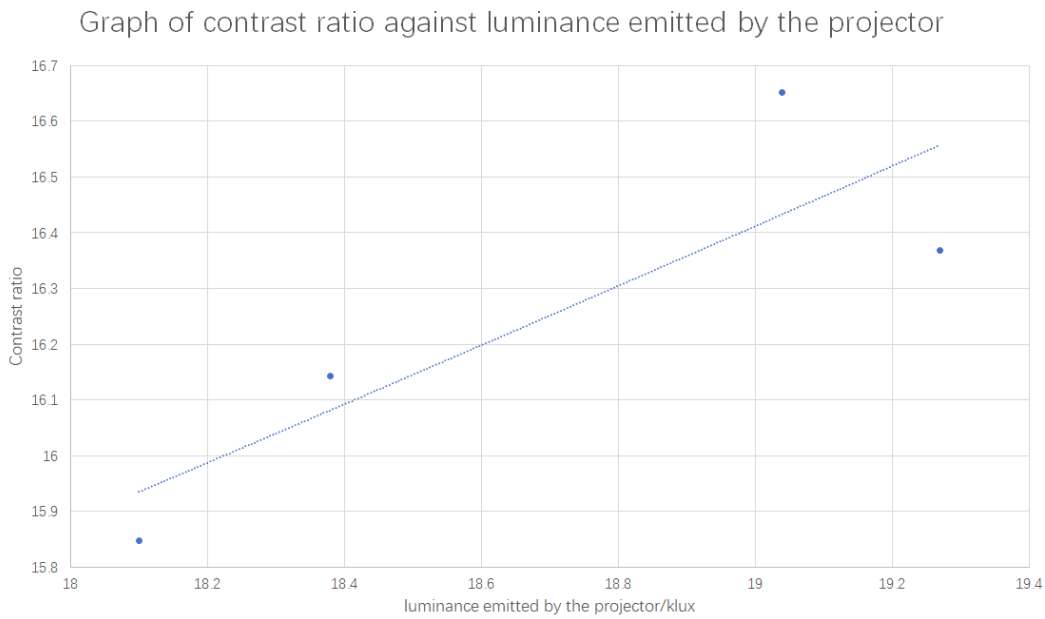


Fig. 5.1 Graph of contrast ratio against luminance emitted by the projector lamp

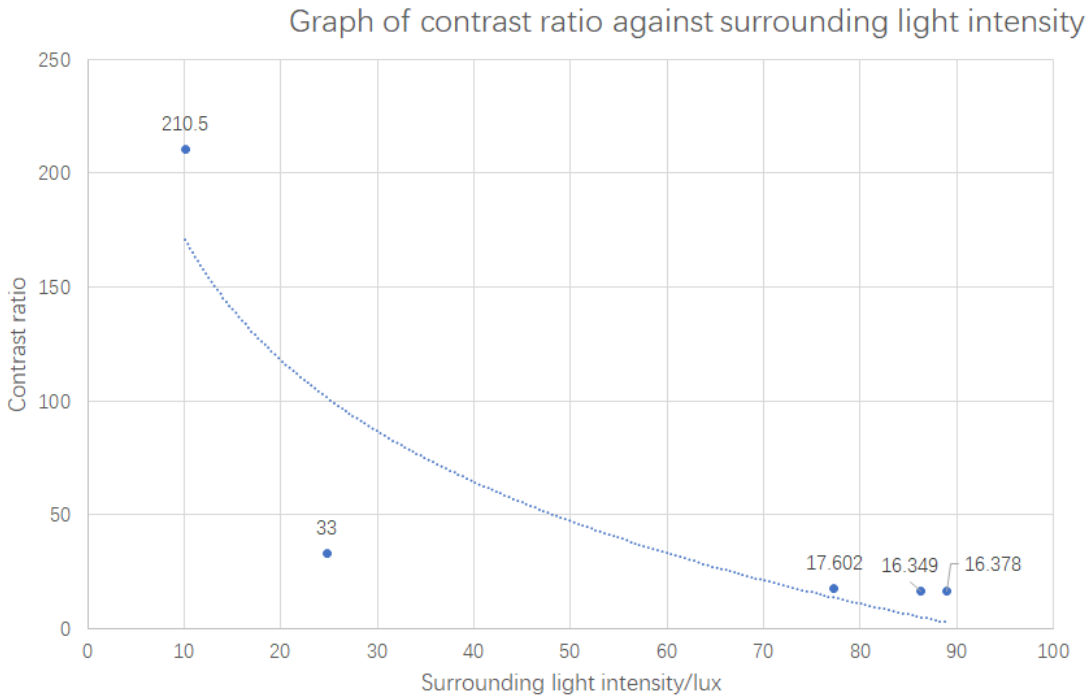
It can be seen that contrast ratio increases as brightness increases, leading to increasing image quality. Hence, in practice, the brightness of the projector lamp should be set to the highest.

5.2 External factors affecting projection quality

5.2.1 Surrounding light intensity

Five different surrounding light intensities were obtained through switching on different numbers of sets of top lights in the laboratory. For each surrounding light intensity, contrast ratio of image projected was measured. The results are shown in Fig. 5.2 and Annex 3

Fig 5.2 Graph of contrast ratio against surrounding light intensity

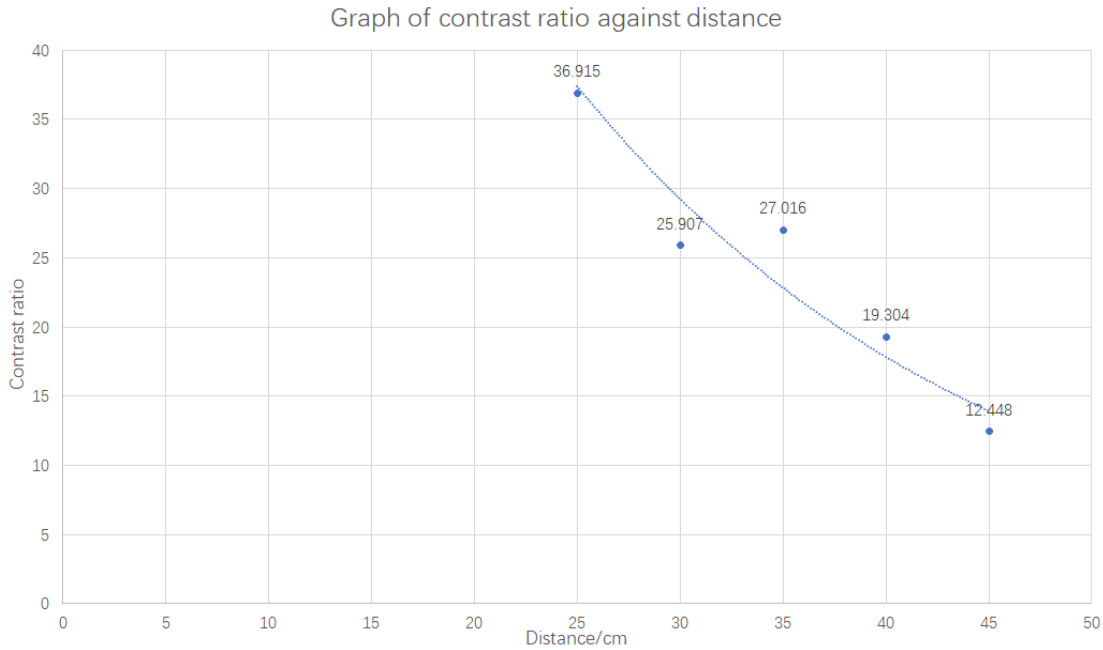


It can be seen that the dimmer the surrounding, the higher the contrast ratio, leading to higher quality of image. Hence, the surrounding should be as dark as possible, and all the lights around the exhibition board should be off in practice, if possible.

5.2.2 Distance from projector to screen

For each of the distances from projector to screen to be 25.0cm, 30.0cm, 35.0cm, 40.0cm, 45.0cm, contrast ratio of image projected was measured. The results are shown in Fig 5.3 and Annex 4.

Fig 5.3 Graph of contrast ratio against distance from projector to screen



It can be seen that when the projector gets closer to the screen, the contrast ratio gets higher, leading to higher projection quality.

Therefore, in practice, the projector needs to be placed as close as possible to the screen. However, trigonometry shows that smaller distance also leads to

smaller size of image, as shown in Fig 5.4

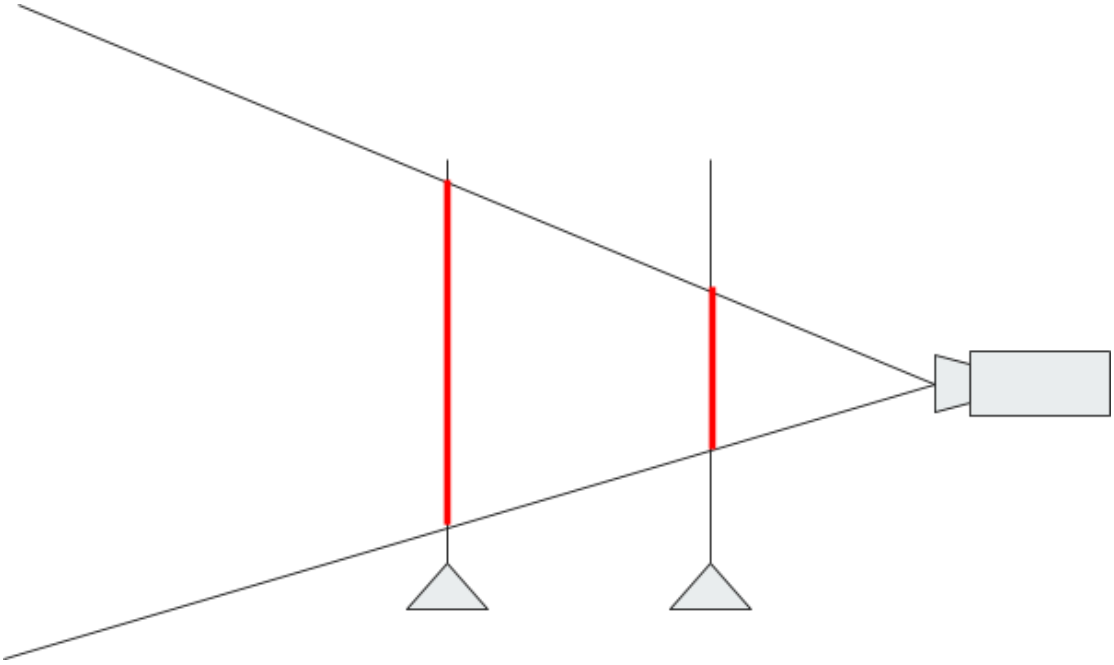


Fig 5.4

But in practice, there are projectors in the market with very small focal length, which allows for smaller distance from projector to the screen without sacrificing size of image, which will be talked about in the later part.

5.3 Integrating an infra-red sensor to Glascene to make it a real interactive exhibition tool

The actual projector used is EPSON EB-1450Ui, paired with an infra-red and multi-touch finger detector which turns the projection screen to a touch screen, as shown in Fig 5.5. In addition, the projector has only 4.2mm of focal length which allows very

small distance from the projector to the screen without sacrificing size of image.

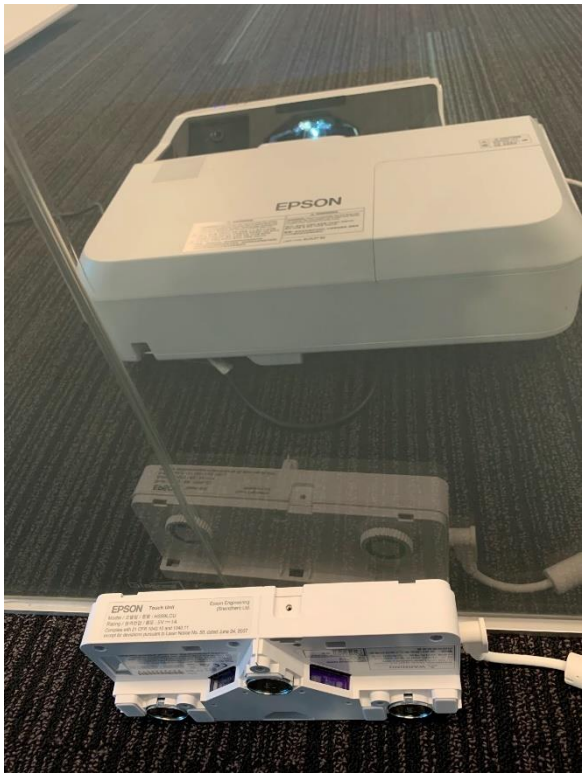


Fig 5.5 EPSON EB-1450Ui

Microsoft PowerPoint was used to develop the interactive user interface. Different slides were linked through hyperlinks, in the form of buttons, and therefore became interactive. Some sample snapshots of the interface can be seen in Fig 5.5

Fig 5.5 A snapshot of interface

In practice, the interface can be operated by the touchscreen. Users can tap the buttons on Glascene to choose and zoom the uniform, as shown in Fig 5.6

Fig 5.6

6)Limitations

6.1 Front-projection screen not used

Although both front and rear projection screens are provided, only rear projection screens were used for experiment due to the experimental methods - If front projection is used, the illuminance meter measuring the contrast ratio of the image will block the light forming image, as shown in Fig 6.1. In the future, raw data from photos such as RGB and illuminance can be used to better quantify contrast ratio and image quality.

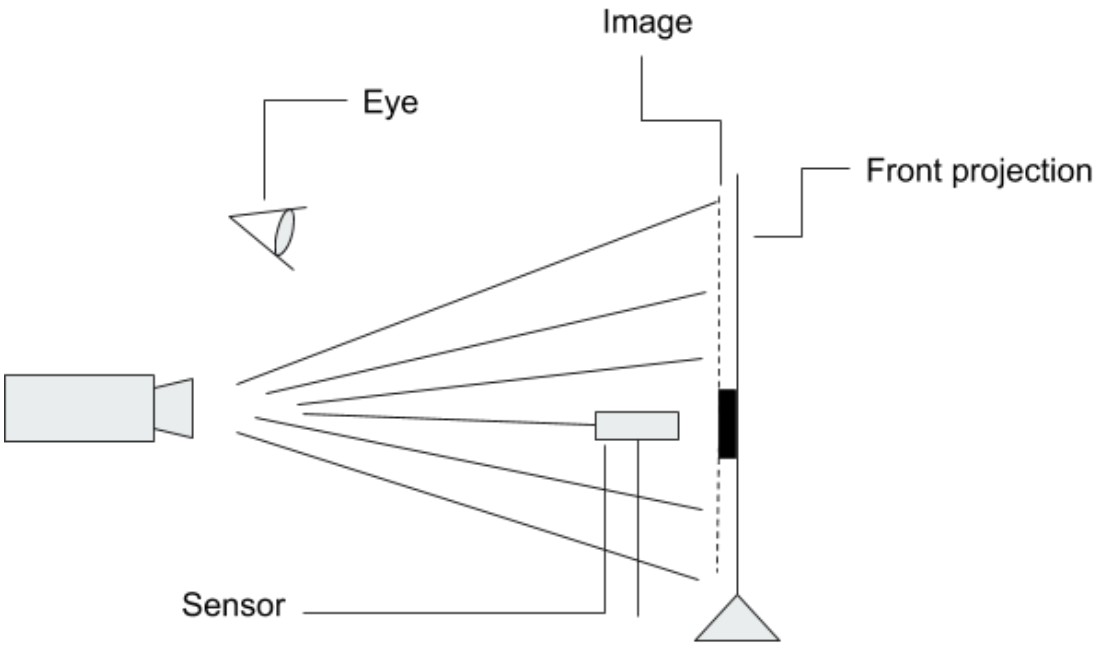


Fig 6.1 Image formed was blocked, leaving a shade

6.2 Limitations regarding of using “contrast ratio” to quantify image quality

Contrast ratio is not the only factor that decides quality of image. There are also other factors, for example, even people’s subjective feelings. Survey regarding front and rear Glascene image quality can be conducted among invited interviewees can be conducted in the future.

6.3 Lack of data

Due to lab conditions, only 5 sets of surrounding light intensity and projector-screen distances and 4 sets of brightness emitted by the projector lamp were taken. In the future, illuminance meter with higher accuracy can be used, box whose light intensity inside can be varied can be designed and wire mouse can be connected to the projector for accurate control over the projector to obtain more data.

6.4 Limitation regarding the final product

Due to the limitation of the height of the projection image, trousers cannot be projected. In the future, projector can be placed vertically for a higher image.

7)Conclusion

Best projection quality requires high contrast ratio of image projected to the screen. From the experiments, lower transparency, higher brightness emitted by the projector lamp, lower surrounding light intensity and lower distance between screen and the projector brought higher contrast ratio, leading to better projection quality.

The final product was an interactive exhibition board which displayed three types of school uniforms commonly seen in Hwa Chong campus - Secondary 3 boys' uniform, Secondary 4/JC boys' uniform and PE T-shirt. People could use Glascene as a touchscreen to select and zoom the uniforms and "wore" them by standing behind the transparent Glascene. The project achieved its set objectives.

8)References

8.1 Gao, X., Chen, X., Zhang, J., & Deng, Z. (2014). Influences of blackboard on teacher's and students' vision and on projection effects in multi-media classroom [Abstract]. Experimental Technology and Management, 31(4). doi:10.16791/j.cnki.sjg.2014.08.017

8.2 AGC Inc. (n.d.). Glascene™ | Products | AGC. Retrieved April 5, 2019, from http://www.agc.com/en/products/new_markets/detail/transparent_glass_screen.html

8.3 Lampert, C. M. (2002, August 29). Large-area smart glass and integrated photovoltaics. Retrieved from https://www.sciencedirect.com/science/article/pii/S0927024802002593

8.4 Kaida, Y., Niiyama, S., Kasai, H., Kamimura, T., Fukui, T., Shiraishi, R., . . . Ogawa, H. (2016, May 25). 13-2: Invited Paper: New "Glass Signage" Manufacturing, "Glass Direct Bonded LCD" and "Transparent Glass Screen". Retrieved from https://onlinelibrary.wiley.com/doi/abs/10.1002/sdtp.10620

8.5. Gao, P., Zhang, Y., Liu, X., & Fan, Z. (2013, June). Scattering polarizer glass screen leading the new technical revolution of transmitting projection screen. Advanced Display, 49-51.

9)Acknowledgements

We would like to express our gratitude to our school mentor, Mrs. Rachel Chan for her invaluable guidance throughout the project; lab staff Mdm. Chua and Mdm. Foo for providing experiment equipment and guiding us through them, external mentor AGC Inc. for Glascene samples and projectors, judges providing constructive suggestions, as well as all other teachers and classmates for their great help.

Annex 1

Independent variable: transparency of glass

Low transparency				High transparency			
White		Black		White		Black	
Time/s	Light Level/lux	Time/s	Light Level/lux	Time/s	Light Level/lux	Time/s	Light Level/lux
0	2180	0	160	0	1650	0	120
0.2	2180	0.2	160	0.2	1650	0.2	120
0.4	2180	0.4	160	0.4	1650	0.4	120
0.6	2180	0.6	155	0.6	1650	0.6	120
0.8	2180	0.8	155	0.8	1650	0.8	120
1	2180	1	155	1	1650	1	120
1.2	2180	1.2	155	1.2	1650	1.2	120
1.4	2180	1.4	155	1.4	1650	1.4	120
1.6	2180	1.6	155	1.6	1650	1.6	120
1.8	2180	1.8	155	1.8	1650	1.8	120
2	2180	2	155	2	1650	2	120
2.2	2180	2.2	155	2.2	1650	2.2	120
2.4	2180	2.4	155	2.4	1650	2.4	120
2.6	2180	2.6	155	2.6	1650	2.6	120
2.8	2180	2.8	155	2.8	1650	2.8	120
3	2180	3	155	3	1650	3	120
3.2	2180	3.2	155	3.2	1650	3.2	120
3.4	2180	3.4	155	3.4	1650	3.4	120
3.6	2180	3.6	155	3.6	1650	3.6	120
3.8	2180	3.8	160	3.8	1650	3.8	120
4	2180	4	160	4	1650	4	120
4.2	2180	4.2	160	4.2	1650	4.2	120
4.4	2180	4.4	160	4.4	1650	4.4	120
4.6	2180	4.6	160	4.6	1650	4.6	120
4.8	2180	4.8	160	4.8	1650	4.8	120
5	2180	5	160	5	1650	5	120
Average	2180	Average	158.4158	Average	1649.554	Average	120.5941
Contrast ratio = 13.761				Contrast ratio = 13.679			

Annex 2

Independent variable: brightness of projector lamp

18.10klux				18.38klux				18.75klux				19.04klux				19.27klux			
White		Black		White		Black		White		Black		White		Black		White		Black	
Time/s	Light Level/lux	Time/s	Light Level/lux	Time/s	Light Level/lux	Time/s	Light Level/lux	Time/s	Light Level/lux	Time/s	Light Level/lux	Time/s	Light Level/lux	Time/s	Light Level/lux	Time/s	Light Level/lux	Time/s	Light Level/lux
0	1695	0	105	0	1695	0	105	0	1695	0	105	0	1660	0	90	0	1695	0	110
0.2	1695	0.2	105	0.2	1695	0.2	105	0.2	1700	0.2	105	0.2	1660	0.2	90	0.2	1695	0.2	110
0.4	1695	0.4	105	0.4	1695	0.4	105	0.4	1700	0.4	105	0.4	1660	0.4	90	0.4	1695	0.4	110
0.6	1695	0.6	105	0.6	1695	0.6	105	0.6	1700	0.6	105	0.6	1660	0.6	90	0.6	1675	0.6	110
0.8	1695	0.8	85	0.8	1695	0.8	105	0.8	1700	0.8	105	0.8	1665	0.8	90	0.8	1665	0.8	110
1	1695	1	95	1	1695	1	105	1	1700	1	105	1	1660	1	90	1	1670	1	105
1.2	1695	1.2	110	1.2	1695	1.2	105	1.2	1700	1.2	105	1.2	1660	1.2	90	1.2	1670	1.2	105
1.4	1695	1.4	105	1.4	1695	1.4	105	1.4	1700	1.4	105	1.4	1660	1.4	90	1.4	1680	1.4	105
1.6	1690	1.6	105	1.6	1695	1.6	105	1.6	1700	1.6	105	1.6	1665	1.6	90	1.6	1675	1.6	105
1.8	1680	1.8	110	1.8	1695	1.8	105	1.8	1700	1.8	105	1.8	1660	1.8	90	1.8	1675	1.8	105
2	1675	2	110	2	1695	2	105	2	1700	2	105	2	1665	2	90	2	1670	2	105
2.2	1675	2.2	110	2.2	1695	2.2	105	2.2	1700	2.2	105	2.2	1665	2.2	90	2.2	1670	2.2	105
2.4	1675	2.4	110	2.4	1695	2.4	105	2.4	1700	2.4	105	2.4	1665	2.4	95	2.4	1670	2.4	105
2.6	1675	2.6	110	2.6	1695	2.6	105	2.6	1700	2.6	105	2.6	1660	2.6	95	2.6	1665	2.6	105
2.8	1675	2.8	110	2.8	1695	2.8	105	2.8	1700	2.8	110	2.8	1665	2.8	95	2.8	1665	2.8	105
3	1675	3	110	3	1695	3	105	3	1700	3	205	3	1665	3	95	3	1665	3	105
3.2	1675	3.2	110	3.2	1695	3.2	105	3.2	1700	3.2	650	3.2	1665	3.2	95	3.2	1665	3.2	105
3.4	1675	3.4	110	3.4	1695	3.4	105	3.4	1700	3.4	835	3.4	1665	3.4	95	3.4	1665	3.4	105
3.6	1675	3.6	110	3.6	1695	3.6	105	3.6	1700	3.6	735	3.6	1665	3.6	90	3.6	1665	3.6	100
3.8	1675	3.8	110	3.8	1695	3.8	105	3.8	1700	3.8	750	3.8	1665	3.8	90	3.8	1665	3.8	100
4	1675	4	110	4	1695	4	105	4	1700	4	735	4	1660	4	90	4	1675	4	100
4.2	1675	4.2	105	4.2	1695	4.2	105	4.2	1700	4.2	725	4.2	1665	4.2	90	4.2	1700	4.2	100
4.4	1675	4.4	105	4.4	1695	4.4	105	4.4	1700	4.4	725	4.4	1665	4.4	90	4.4	1695	4.4	100
4.6	1675	4.6	105	4.6	1695	4.6	105	4.6	1700	4.6	705	4.6	1665	4.6	90	4.6	1695	4.6	100
4.8	1675	4.8	105	4.8	1695	4.8	105	4.8	1700	4.8	720	4.8	1665	4.8	90	4.8	1695	4.8	100
5	1675	5	105	5	1695	5	105	5	1700	5	480	5	1665	5	90	5	1695	5	100
Average	1686.832	Average	106.4356	Average	1695	Average	105	Average	1699.95	Average	230.9406	Average	1665.248	Average	92.37624	Average	1692.723	Average	103.4158
Contrast ratio = 15.848				Contrast ratio = 16.143				Contrast ratio =7.3610				Contrast ratio = 18.027				Contrast ratio = 16.368			

Annex 3

Independent variable: Surrounding light intensity

10.1lux				24.8lux				77.3lux				86.3lux				88.9lux			
White		Black		White		Black		White		Black		White		Black		White		Black	
Time/s	Light Level/lux	Time/s	Light Leve/lux	Time/s	Light Level/lux	Time/s	Light Level/lux	Time/s	Light Level/lux	Time/s	Light Level/lux	Time/s	Light Level/lux	Time/s	Light Level/lux	Time/s	Light Level/lux	Time/ s	Light Level/lux
0	2105	0	10	0	2150	0	65	0	2195	0	125	0	2205	0	135	0	2210	0	135
0.2	2105	0.2	10	0.2	2150	0.2	65	0.2	2195	0.2	125	0.2	2205	0.2	135	0.2	2210	0.2	135
0.4	2105	0.4	10	0.4	2150	0.4	65	0.4	2195	0.4	125	0.4	2205	0.4	135	0.4	2210	0.4	135
0.6	2105	0.6	10	0.6	2150	0.6	65	0.6	2195	0.6	125	0.6	2205	0.6	135	0.6	2210	0.6	135
0.8	2105	0.8	10	0.8	2150	0.8	65	0.8	2195	0.8	125	0.8	2205	0.8	135	0.8	2210	0.8	135
1	2105	1	10	1	2150	1	65	1	2195	1	125	1	2205	1	135	1	2210	1	135
1.2	2105	1.2	10	1.2	2150	1.2	65	1.2	2195	1.2	125	1.2	2205	1.2	135	1.2	2210	1.2	135
1.4	2105	1.4	10	1.4	2150	1.4	65	1.4	2195	1.4	120	1.4	2205	1.4	135	1.4	2210	1.4	135
1.6	2105	1.6	10	1.6	2150	1.6	65	1.6	2195	1.6	125	1.6	2205	1.6	135	1.6	2210	1.6	135
1.8	2105	1.8	10	1.8	2150	1.8	65	1.8	2195	1.8	125	1.8	2205	1.8	135	1.8	2210	1.8	135
2	2105	2	10	2	2150	2	65	2	2195	2	125	2	2205	2	135	2	2210	2	135
2.2	2105	2.2	10	2.2	2150	2.2	65	2.2	2195	2.2	120	2.2	2205	2.2	135	2.2	2210	2.2	135
2.4	2105	2.4	10	2.4	2150	2.4	65	2.4	2195	2.4	125	2.4	2205	2.4	135	2.4	2210	2.4	135
2.6	2105	2.6	10	2.6	2155	2.6	65	2.6	2195	2.6	125	2.6	2205	2.6	135	2.6	2210	2.6	135
2.8	2105	2.8	10	2.8	2150	2.8	65	2.8	2195	2.8	125	2.8	2205	2.8	135	2.8	2210	2.8	135
3	2105	3	10	3	2155	3	65	3	2195	3	125	3	2205	3	135	3	2210	3	135
3.2	2105	3.2	10	3.2	2155	3.2	65	3.2	2195	3.2	125	3.2	2205	3.2	135	3.2	2210	3.2	135
3.4	2105	3.4	10	3.4	2150	3.4	65	3.4	2195	3.4	125	3.4	2205	3.4	135	3.4	2210	3.4	135
3.6	2105	3.6	10	3.6	2150	3.6	65	3.6	2195	3.6	125	3.6	2205	3.6	135	3.6	2210	3.6	135
3.8	2105	3.8	10	3.8	2155	3.8	65	3.8	2195	3.8	125	3.8	2205	3.8	135	3.8	2210	3.8	135
4	2105	4	10	4	2155	4	65	4	2195	4	125	4	2205	4	135	4	2210	4	135
4.2	2105	4.2	10	4.2	2155	4.2	65	4.2	2195	4.2	125	4.2	2205	4.2	135	4.2	2210	4.2	135
4.4	2105	4.4	10	4.4	2155	4.4	65	4.4	2195	4.4	125	4.4	2205	4.4	135	4.4	2210	4.4	135
4.6	2105	4.6	10	4.6	2155	4.6	65	4.6	2195	4.6	125	4.6	2205	4.6	135	4.6	2210	4.6	135
4.8	2105	4.8	10	4.8	2155	4.8	65	4.8	2195	4.8	125	4.8	2205	4.8	135	4.8	2210	4.8	135
5	2105	5	10	5	2155	5	65	5	2200	5	125	5	2205	5	135	5	2210	5	135
Average	2105	Average	10	Average	2154.208	Average	65	Average	2198.465	Average	124.901	Average	2207.178	Average	135	Average	2211.089	Average	135
Contrast ratio = 210.50				Contrast ratio = 33.142				Contrast ratio =17.602				Contrast ratio = 16.349				Contrast ratio = 16.378			

Annex 4

Independent variable: distance between screen and glass

25.0cm				30.0cm				35.0cm				40.0cm				45.0cm			
White		Black		White		Black		White		Black		White		Black		White		Black	
Time/s	Light Level/lux	Time/s	Light Level/lux	Time/s	Light Level/lux	Time/s	Light Level/lux	Time/s	Light Level/lux	Time/s	Light Level/lux	Time/s	Light Level/lux	Time/s	Light Level/lux	Time/s	Light Level/lux	Time/s	Light Level/lux
0	4065	0	110	0	2980	0	115	0	2175	0	80	0	1705	0	90	0	1350	0	110
0.2	4065	0.2	110	0.2	2980	0.2	115	0.2	2170	0.2	80	0.2	1705	0.2	90	0.2	1350	0.2	110
0.4	4065	0.4	110	0.4	2980	0.4	115	0.4	2165	0.4	80	0.4	1705	0.4	90	0.4	1350	0.4	110
0.6	4065	0.6	110	0.6	2975	0.6	115	0.6	2165	0.6	80	0.6	1705	0.6	90	0.6	1350	0.6	110
0.8	4065	0.8	110	0.8	2975	0.8	115	0.8	2170	0.8	80	0.8	1705	0.8	90	0.8	1345	0.8	110
1	4065	1	110	1	2975	1	115	1	2170	1	80	1	1705	1	90	1	1350	1	110
1.2	4065	1.2	110	1.2	2975	1.2	115	1.2	2170	1.2	80	1.2	1705	1.2	90	1.2	1350	1.2	110
1.4	4065	1.4	110	1.4	2975	1.4	115	1.4	2170	1.4	80	1.4	1705	1.4	90	1.4	1350	1.4	110
1.6	4065	1.6	110	1.6	2975	1.6	115	1.6	2170	1.6	80	1.6	1705	1.6	90	1.6	1345	1.6	110
1.8	4065	1.8	110	1.8	2980	1.8	115	1.8	2170	1.8	80	1.8	1705	1.8	90	1.8	1345	1.8	110
2	4065	2	110	2	2980	2	115	2	2170	2	80	2	1705	2	90	2	1345	2	110
2.2	4065	2.2	110	2.2	2980	2.2	115	2.2	2170	2.2	80	2.2	1705	2.2	90	2.2	1345	2.2	110
2.4	4065	2.4	110	2.4	2980	2.4	115	2.4	2170	2.4	80	2.4	1705	2.4	90	2.4	1345	2.4	110
2.6	4065	2.6	110	2.6	2980	2.6	115	2.6	2170	2.6	80	2.6	1705	2.6	90	2.6	1345	2.6	105
2.8	4065	2.8	110	2.8	2980	2.8	115	2.8	2170	2.8	80	2.8	1705	2.8	90	2.8	1345	2.8	105
3	4065	3	110	3	2980	3	115	3	2170	3	80	3	1705	3	90	3	1345	3	105
3.2	4065	3.2	110	3.2	2980	3.2	115	3.2	2170	3.2	80	3.2	1705	3.2	90	3.2	1350	3.2	105
3.4	4065	3.4	110	3.4	2980	3.4	115	3.4	2170	3.4	80	3.4	1705	3.4	90	3.4	1350	3.4	105
3.6	4065	3.6	110	3.6	2980	3.6	115	3.6	2170	3.6	80	3.6	1705	3.6	90	3.6	1350	3.6	105
3.8	4065	3.8	110	3.8	2980	3.8	115	3.8	2170	3.8	80	3.8	1705	3.8	90	3.8	1350	3.8	105
4	4065	4	110	4	2980	4	115	4	2170	4	80	4	1705	4	90	4	1350	4	105
4.2	4065	4.2	110	4.2	2980	4.2	115	4.2	2170	4.2	80	4.2	1705	4.2	90	4.2	1350	4.2	105
4.4	4065	4.4	110	4.4	2980	4.4	115	4.4	2170	4.4	80	4.4	1705	4.4	90	4.4	1350	4.4	105
4.6	4065	4.6	110	4.6	2980	4.6	115	4.6	2170	4.6	80	4.6	1705	4.6	90	4.6	1350	4.6	105
4.8	4065	4.8	110	4.8	2980	4.8	115	4.8	2170	4.8	80	4.8	1705	4.8	90	4.8	1350	4.8	105
5	4065	5	110	5	2980	5	115	5	2170	5	80	5	1705	5	90	5	1350	5	105
Average	4060.693	Average	110	Average	2979.307	Average	115	Average	2161.287129	Average	80	Average	1704.851	Average	88.31683	Average	1349.554	Average	108.4158
Contrast ratio = 36.915				Contrast ratio = 25.907				Contrast ratio = 27.016				Contrast ratio = 19.304				Contrast ratio = 12.448			