Using the capability of Mantis Shrimp Eyes for medical imaging

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Abstract

Mantis shrimp are animals that have eyes which can detect both linearly and circularly polarised light. Polarised light refers to light that vibrates only in a single plane. Current research also shows that cancer cells do not reflect polarised light, while healthy cells do. As of now, cancer detection methods are often time-consuming and inconvenient. This results in many people not going for cancer check-ups regularly, and hence many people are only diagnosed with cancer at the later stages, where treatment is often difficult. This project is aimed to to find a method of cancer detection that is both easy and convenient to use. Based on the way that mantis shrimp detect polarised light, and the fact that cancer cells reflect unpolarised light, a device was made to detect the amount of light that passed through a sample of cells. A greater intensity of light would indicate that the light was largely unpolarised and hence the sample was most likely to contain unhealthy cells. A trend could be observed in the amount of light passing through a sample of both healthy and unhealthy cells, simulated using a polariser for healthy cells and a clear sheet for unhealthy cells. This showed that the device could possibly determine the amount of unhealthy cells in a certain cell sample.

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1.0 Introduction

1.1 Motivation of our research

The problem identified in this research is that current existing cancer detection methods are often time-consuming and inconvenient. These factors deter people from going for regular cancer check-ups, hence resulting in many people discovering that they are diagnosed with cancer at a very late stage, making it too late for treatment. In the United States of America, 2018, over 1.6 million new cancer cases were diagnosed and more than 595,000 people died from cancer. According to data collected by England's National Health Service, 46% of all cancers diagnosed in England in 2012 were not detected until they had reached stage 3 or 4. This implied that cancers were usually only detected in late stages when it became difficult to cure or could result in death.

The goal of this research is to create a cancer detection device using the concept of how cancer cells do not reflect polarised light while healthy cells do, to detect the presence of cancer cells in a cell sample, possibly making the process faster than conventional cancer detection methods. This may help to detect cancers earlier by providing an easier and more convenient method of cancer detection so more people will be willing to go for regular cancer check-ups and cancer will be detected early.

1.2 Mantis Shrimp

This research is mainly inspired by the scientific concepts behind the amazing vision of the mantis shrimp. Mantis shrimp eyes have many different capabilities like trinocular vision and the ability to see twelve colours in the light spectrum. However, one significant feature of their eyes is the ability to detect both linearly and circularly polarised light, which is something the naked human eye cannot do, as humans can only detect unpolarised, normal white light that is seen in people's everyday lives. The extraordinary vision of mantis shrimp enables them to see their prey better underwater through circularly polarised light that is reflected into their eyes from their prey. The concept of reflection and detection of polarised light was applied onto the detection of cancer cells, as cancer cells do not reflect polarised light while normal healthy cells do.

1.3 Polarised Light

The normal light that comes from the Sun which is reflected into human eyes and enables people to see the world is known as unpolarised light. Unpolarised light rays travel in all directions and vibrate in more than one plane. Light can be polarised by a polariser which either absorbs or blocks light oscillating in different planes than what it was calibrated for. This reduces the final intensity of light that passes through the polariser. When there are 2 or more polarisers, the intensity of light varies based on the angle between their polarisation axes, as more light rays will be blocked when the angle between the polarisers and thus the angle between the plane that the light rays are able to oscillate in increase. Besides the angle of polarisation, the degree of polarisation, which is the extent that the light is polarised, also affects how the light will be polarised. This varies with how much light passes through the polariser.

1.4 Current Research

Cancer cells do not reflect polarised light at the same intensity as healthy cells (Liu et. al. 2012). Thus when a ray of polarised light is passed through a sample of cancer cells and another sample of healthy cells, the resultant amount of light from the cancer cell experiment would be less than that of the healthy cell experiment.

Light can be used for faster measurements, only limited by how fast information can be processed since the speed of light is 3.0×10^8 ms^{-1}. In research, a charge-coupled device, which is used to create an image of the specimen, has a range of between 0.1 MHz to 2.0 MHz and the datalogger this research uses has a range of 5 Hz. Even at that range while also considering the need to measure various angles, the method is still much faster and more efficient than spending days or even weeks to detect cancer using current methods.

1.5 Research Objective

By calculating the intensity of the light-emitting diode (LED) light against the angle of polarisation, as well as accounting for the attenuation of light by the specimen, the degree of polarisation which is directly linked to the presence of cancer cells could be found. This method could be quicker than current methods of detecting cancer cells.

This research aimed to show that this method of detecting cancer cells had the potential to be more effective than current solutions.

2.0 Methodology

2.1 Set-up

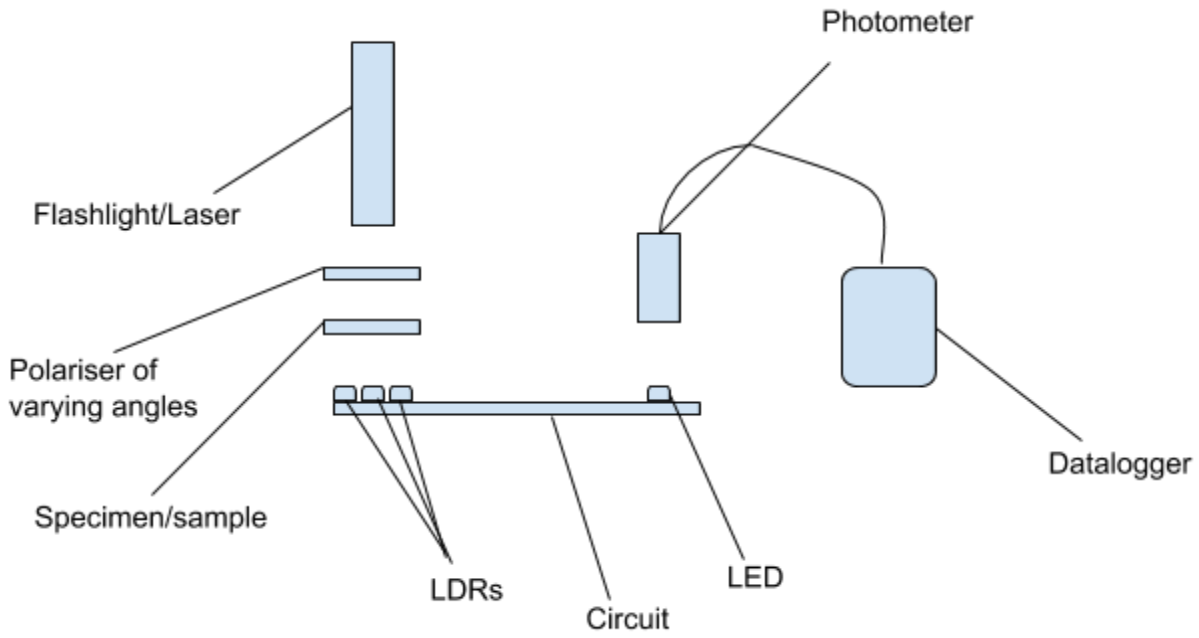

Figure 1.0

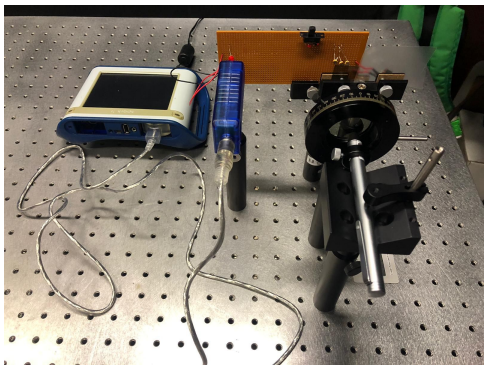

Figure 1.1

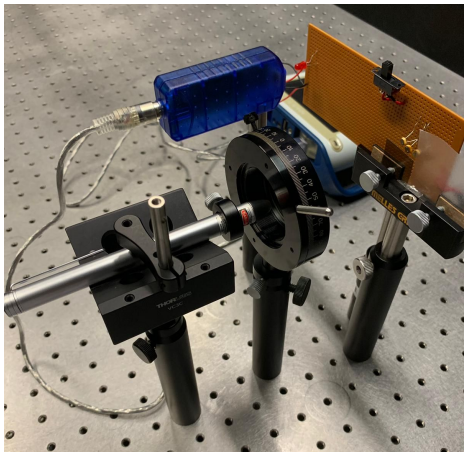

Figure 1.2

Using optical mounting equipment, the instruments were fixed in place on a flat surface after measurement (using the laser to pinpoint the spot that it was shining at) such that they were in alignment. The space between the various instruments was minimised so as to minimise the amount of light scattered by the air spaces in between. The experimental set-up was put in the

dark room which would ensure that there would be minimal surrounding light that could be detected by the photometer. (Light intensity reading when circuit and lights were off in the dark room was 0 lux.) The polariser of varying angles has markings of 1° so the precision is 0.5°. The range of marking was from -90° to 90°. The torchlight or laser was fixed in place by screws. The sample was also fixed in place by screws and samples which were small enough to be set perpendicular to the flat surface with negligible deflection. The circuit board was also mounted in place with screws, such that the area between the photometer and the LED was unchanged throughout the experiment.

2.2 Circuit

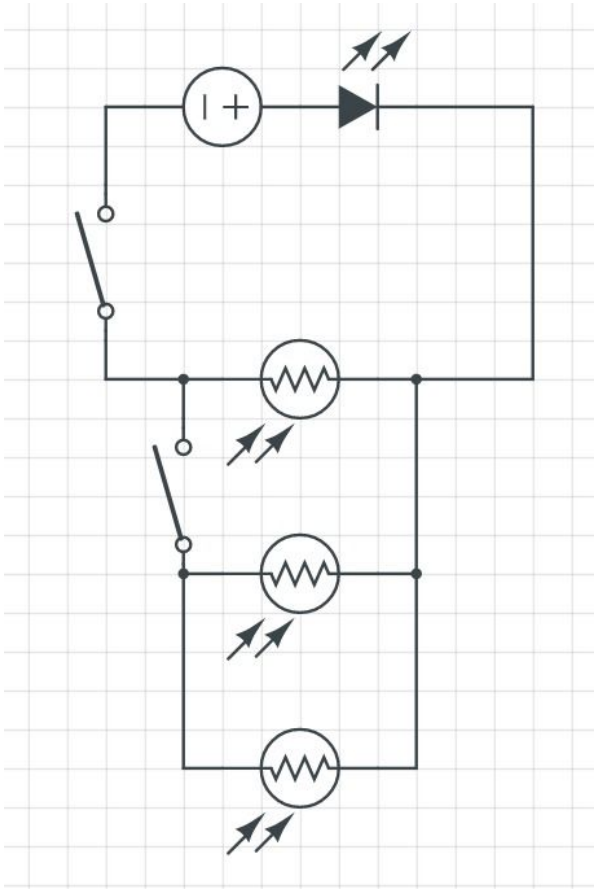

Figure 2.0

The circuit was soldered to a PCB (printed circuit board), where the light-dependent resistors (LDRs) were connected in parallel with one another and in series to the LED. The main switch

was used to control the whole circuit while the second switch toggled the activation of the other 2 LDRs (necessary as the laser light was not wide enough to shine on all 3 LDRs at once). By increasing the number of LDRs in parallel, the total resistance was decreased, resulting in an increase in current passing through the circuit and hence the power of the LED. This allowed for greater variance in readings of the intensity of the LED, and the results could thus be more accurate with a wider range of values (else values would be below 20 lux).

2.3 Data Collection

2.3.1 Intensity of LED against angle of polarisation

2.3.1.1 Torchlight

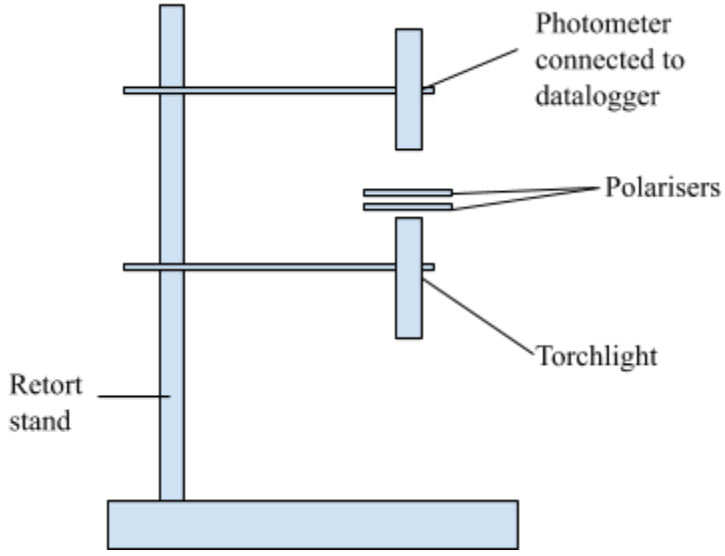

Figure 2.1

The angle of polarisation was changed manually by adjusting the angle of one polariser against a protractor and keeping the angle of the other polariser the same throughout the experiment. The infrared laser was calibrated to be at 90° to the sample. A polariser of varying intensity was calibrated such that it would be at 0° to the laser light when adjusted to the 0° mark. Values were taken in intervals of 5° from 0° to 180°. A graph was plotted of intensity of light of LED against angle of polarisation.

This would be able to determine whether the sample polarises light by identifying whether the intensity of the LED changes based on the angle of polarisation. This was because as the angle between the 2 polarisers approaches 90°, more light would be blocked.

2.3.1.2 Laser

Using the set-up in Fig. 1, values were taken in intervals 5° from -90° to 90°. The laser was used to more accurately measure the intensity of the LED against the angle of polarisation since there would be a greater range of values. A graph was plotted of intensity of LED against angle of polarisation.

This was a more detailed version of the previous experiment which uses 3 polarisers instead of 2. It determined the change in the intensity of the LED based on the angle of polarisation when there were 3 polarisers.

2.3.2 Intensity of LED against thickness of clear sheet

Using the torchlight in the set-up in Fig. 1, various thicknesses of the clear sheet were used ranging from 0.006cm to 0.024cm in intervals of 0.006cm. The average intensity of light produced by the LED was recorded. A graph was plotted using Google Sheets.

This would show the relationship between the thickness of the specimen and the intensity of the LED. By calculating the attenuation coefficient, we can also predict what the intensity would be for various thicknesses of the material, and it can be confirmed by carrying out the experiment itself. This is also known as the concept of the attenuation of light, where light is scattered and absorbed to a greater extent as the thickness of the material increases.

2.3.3 Intensity of LED against proportional degree of polarisation

Using the torchlight and set-up in Fig. 1 with all 3 LDRs connected, the datalogger was used to plot a graph while the angle of polarisation was changed manually. The maximum and minimum intensities of light were recorded. This, however, was processed data. The degree of polarisation

was varied by covering different fractions of the LDRs with a polariser, while the others were covered with a clear sheet of 0.006cm. The experiment was carried out with no LDRs covered by a polariser, half, one, one and a half, two, two and a half and finally three LDRs covered by a polariser. A graph was plotted using Google Sheets.

This would determine the relationship between the degree of polarisation and variance in the intensity of the LED. The degree of polarisation would affect how much the intensity of the LED would be able to vary, resulting in greater variance as the degree of polarisation increases.

3.0 Results & Discussion

3.1 Use of use of varying angles of polarised light to detect presence of polariser

3.1.1 2 Polarisers and torchlight

Figure 3.0 showed the relationship between the angle of polarisation between 2 polarisers and the intensity of light from the light source, which follows the relationship of $I = I_o\cos^2\theta$, where I is the final intensity of light, I_o is the original intensity of light and θ is the angle of polarisation. The theoretical value of the intensity of light at $\theta = 90°$ is 0, however this was not the case as shown in the graph as in the actual experiment, some light was still able to pass through the 2 polarisers even when they are at 90° to each other, likely because of the air in between the polarisers or scratches on the polariser.

Results from the experiment showed that if testing whether a substance polarises light, by recording a graph of how the intensity changes as the AoP changes, when the graph had a similar shape, it could be concluded that the substance polarises light.

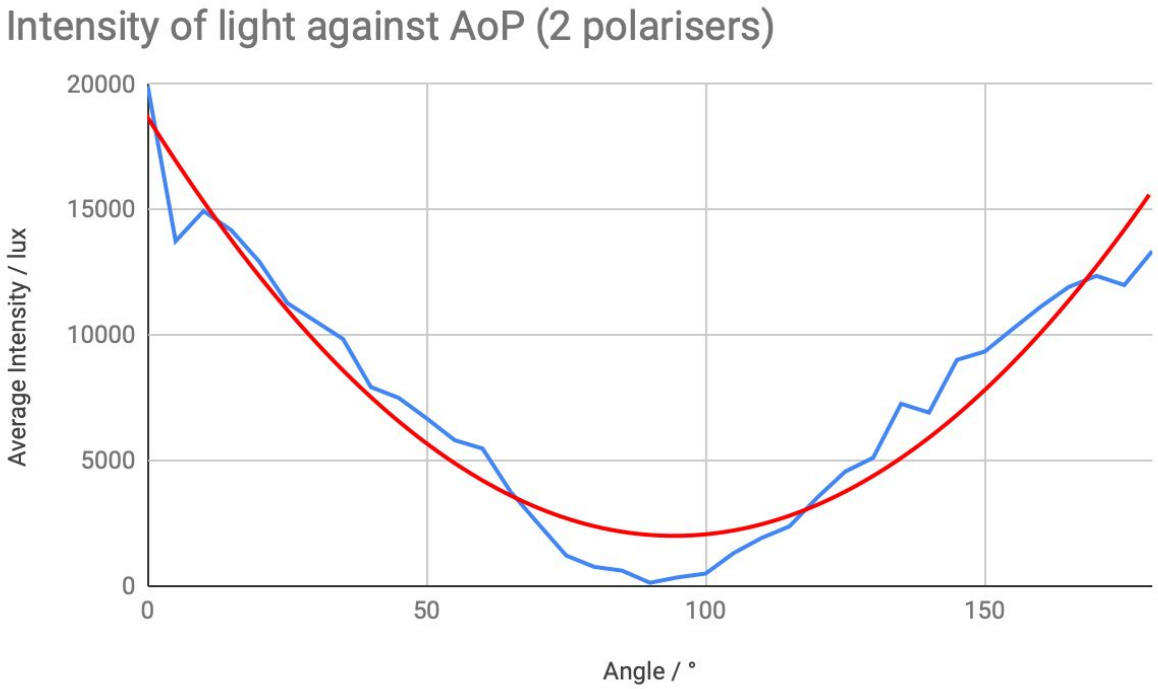

Figure 3.0

3.1.2 2 Polarisers and laser

Figure 3.1 showed the relationship between the angle of polarisation between 3 polarisers and the intensity of light from the LED. It was shown that the intensity of light was at a maximum when the angle of polarisation is around -45° and 45°, while it was at a minimum at around -90°, 0° and 90°.

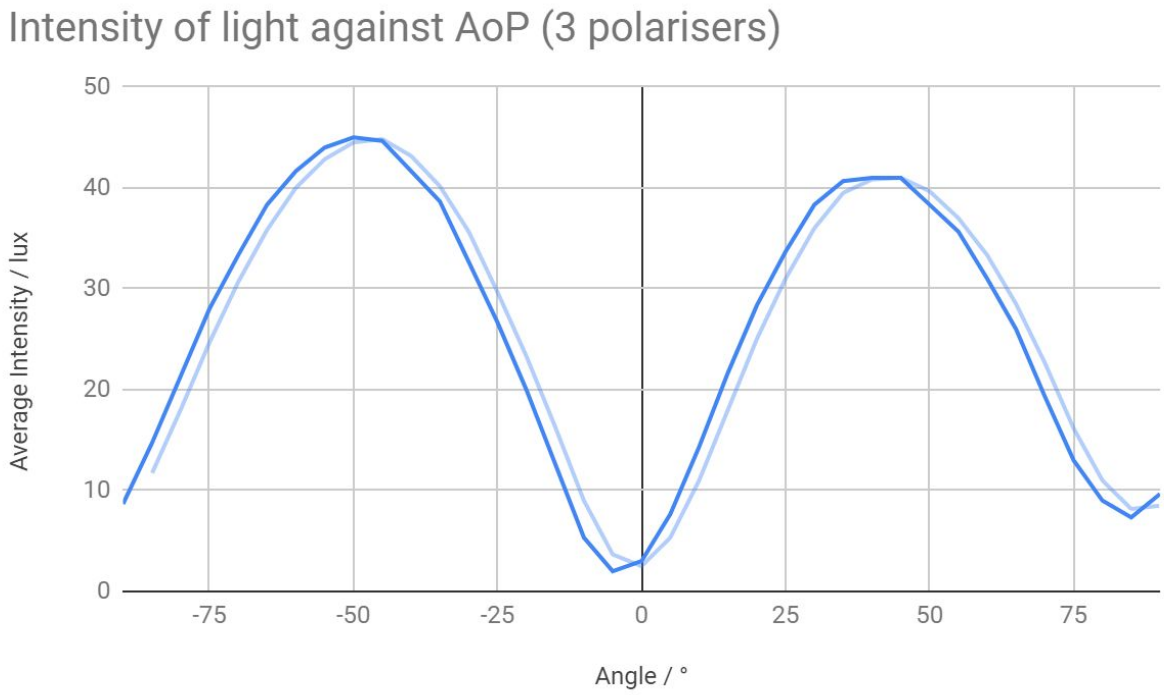

Figure 3.1

Both the relationships explored in 3.1.1 and 3.1.2 regarding the intensity of light against the angle of polarisation were used to determine how the polarisation effect of a sample of unhealthy cells would affect the intensity of light as well. If a polariser that was used in either of the tests were to be replaced by a sample largely consisting of unhealthy cells, it would very possibly follow the same relationship with how the intensity of light changes as the angle of polarisation changes, between both 2 and 3 polarisers.

3.2 Use of variance between maximum and minimum light intensity to determine the degree of polarisation

Figure 3.2 showed the relationship between the number of LDRs that were covered with polarisers and the intensity of light from the LED. It was shown that as the number of LDRs covered with polarisers increases, the difference between the maximum and minimum resultant intensity of light increases as well.

Results from the experiment showed that the proportionate degree of polarisation could be measured by comparing the values taken from a specimen to a set of data, such as this graph. By pinpointing where the values lie, the extent to which the specimen could polarise light was determined.

Number of LDRs receiving polarised light	Average maximum intensity / lux	Average minimum intensity / lux	Difference in maximum and minimum intensity / lux
0	8.3	8.0	0.33
0.5	9.3	7.8	1.5
1	8.3	5.2	3.2
1.5	7.0	2.0	5.0
2	7.8	1.5	6.3
2.5	7.5	1.2	6.3
3	7.2	0.17	7.0

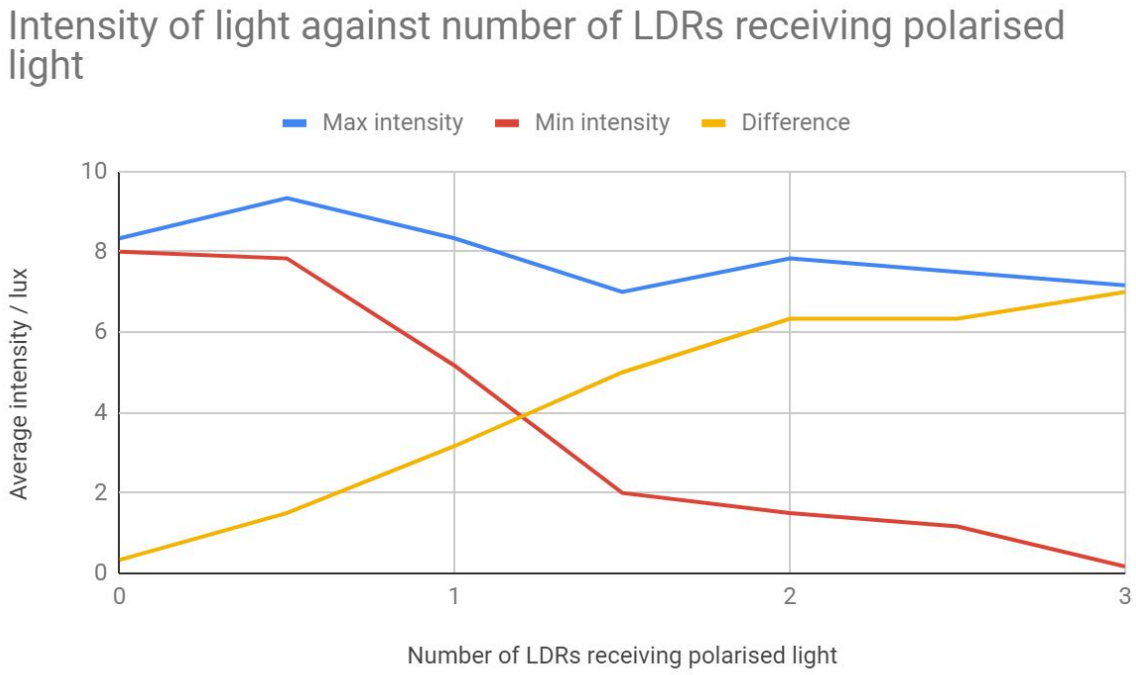

Figure 3.2

When using an actual cell sample, it would be possible to find the extent to which the sample polarises light, based on the difference between the maximum and minimum intensity of light obtained from the LED. When there was little to no difference in the maximum and minimum intensity of light from the LED, it could be concluded that the sample polarises light either to an extremely small extent or even to no extent at all; hence it would most likely be a sample largely consisting of unhealthy cells. Likewise, when there was a greater difference in the maximum and minimum intensity of light from the LED, it could be concluded that the sample polarises light to a large extent; hence it would most likely be a sample which consisted of little to no unhealthy cells.

3.3 Use of attenuation coefficient to account for thickness of specimen/sample

Figure 3.3 showed the relationship between the thickness of the clear sheet and the intensity of light from the LED. It was shown that as the thickness of the clear sheet increases, the resultant intensity of light decreases.

Results from this experiment showed that the attenuation coefficient of the substance could be used to account for any change in light intensity, so when the values were measured, by calculating what the intensity should be rather than what was measured, it can be determined how much change in intensity was caused by polarisation rather than simply the scattering or absorption of light by the specimen.

Thickness / cm	Intensity / lux
0.006	11
0.012	6.0
0.018	5.5
0.024	4.5
0.030	4.0
0.036	3.5

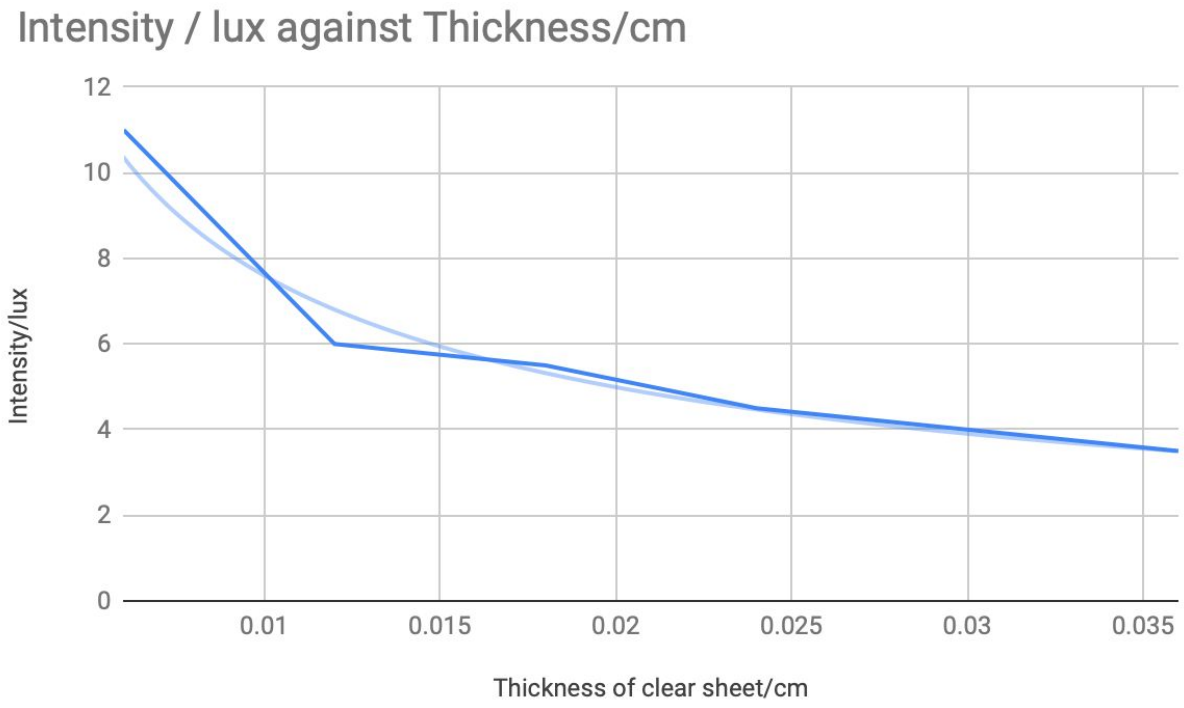

Figure 3.3

The final intensity of light after it has been scattered or absorbed by a material is given by $I = I_o e^{-\mu x}$. I is the final intensity of light, I_o is the original intensity of light, μ is the attenuation

coefficient of the given material (measured in cm^{-1}) and x is the thickness of the given material (measured in cm). This equation was also used to find the attenuation coefficient of any material or sample, based on the final intensity of light as well as the thickness of the material or sample.

3.4 Use of plant cells to determine change in light intensity

3.4.1 Angle of Polarisation

In order to determine how the intensity of light from the LED would change using an actual sample of healthy cells, plant cells were used as the sample for the setup. The attenuation coefficient of the plant cells used, which were onion and potato cells, were first determined by measuring the different thicknesses and measuring the original and final intensity of light passing through the cell samples. This was done such that when determining the change in intensity using the different plant cell samples, the attenuation coefficient of each cell sample could also be taken into account.

Onion sample	Original intensity = 9200 lux	Average μ = 7.60			
Thickness / cm	Intensity 1 / lux	Intensity 2 / lux	Intensity 3 / lux	Average intensity / lux	μ / cm^{-1}
0.261	1295	1294	1296	1295	7.51
0.318	585	584	584	584.3	8.69
0.595	182	183	182	182.3	6.59

Potato sample	Original intensity = 7970 lux	Average μ = 10.9			
Thickness / cm	Intensity 1 / lux	Intensity 2 / lux	Intensity 3 / lux	Average intensity / lux	μ / cm^{-1}
0.255	815	800	805	807	9.54
0.261	440	460	460	453	11.5
0.286	280	270	290	280	11.7

Following this, the relationships between the intensity of light from the LED and the angle of polarisation between the polariser and the different plant cell samples were observed.

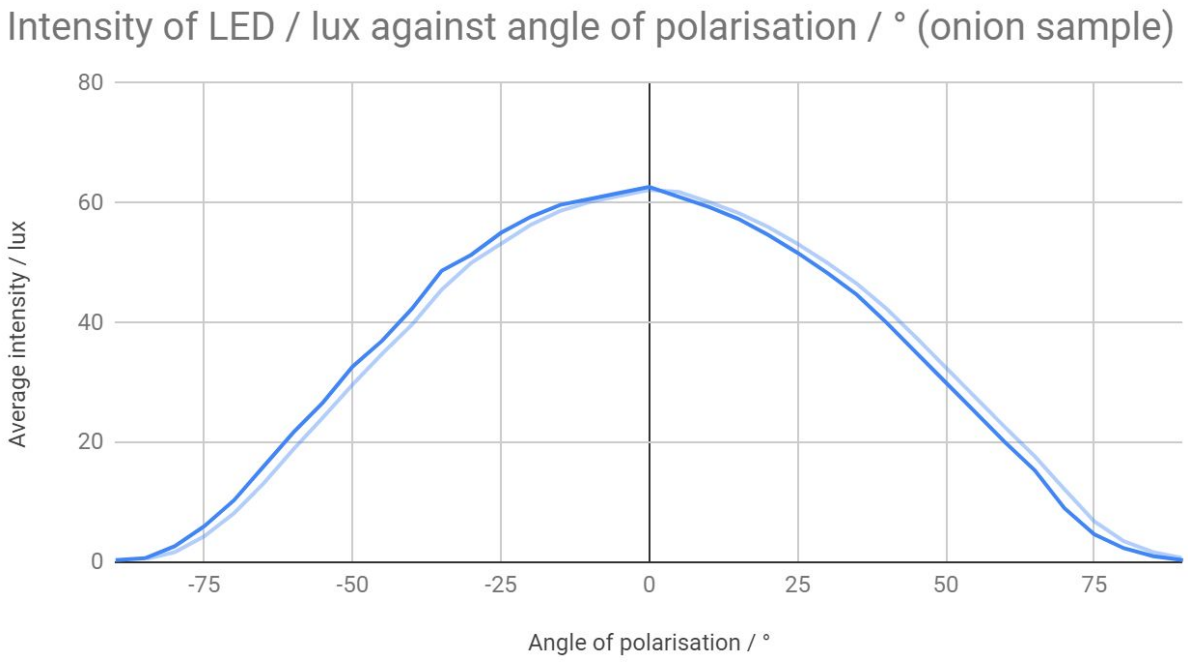

Figure 3.4

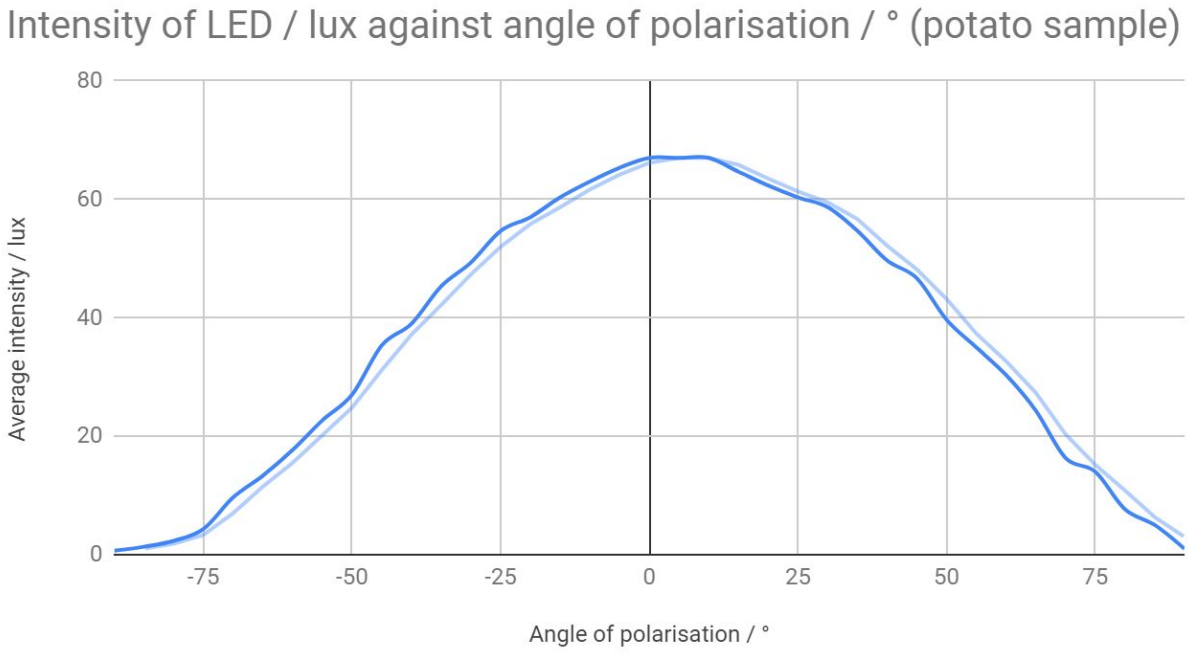

Figure 3.5

The plant cells which were healthy cell samples also reflected polarised light, similar to the polariser from previous tests. This explains why when the angle of polarisation was 0°, the most

amount of light passed through the cell sample, and with the greatest intensity of light shining on the LDRs, the intensity of light from the LED was also a maximum. Meanwhile, at -90° and 90°, the least amount of light passed through the cell sample, and with the smallest intensity of light shining on the LDRs, the intensity of light from the LED was at a minimum.

3.4.2 Degree of Polarisation

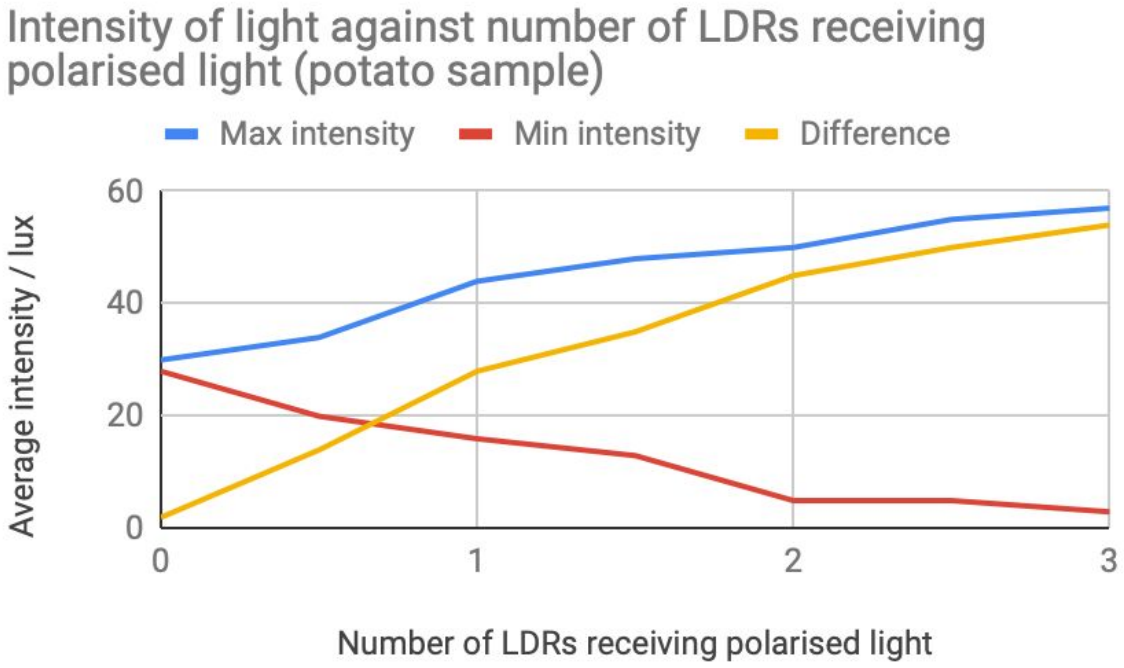

Figure 3.6

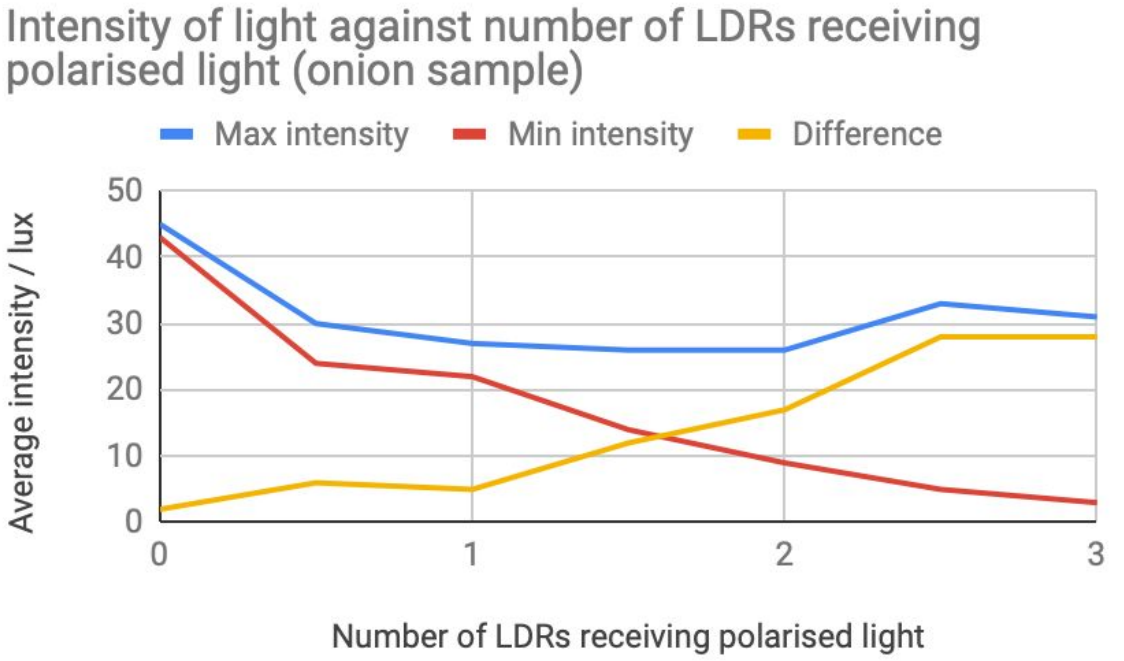

Figure 3.7

Figures 3.6 and 3.7 show that as the number of LDRs receiving light that passed through a plant cell sample increased, the difference between the maximum and minimum intensity increased. This showed that the plant cells, which reflect polarised light, did affect the degree of polarisation. Since plant cells and human cells are very similar, this set-up would be able to determine the degree of polarisation for human cells as well.

3.5 Limitations

Some of the limitations of this set-up include that the research was unable to use a sample of actual cancer cells to test with the set-up. To get by this, a sample of cells was replicated using a clear sheet instead. The clear sheet had an attenuation coefficient of 7.91 while a sample of cells would have an attenuation coefficient of between 16.3 to 100, hence the results that were obtained would have been slightly different than if an actual sample of cancer cells were to be used for calculations instead. Even after using a plant cell, which would be more similar to human cells, its attenuation coefficient still would not be equal to the expected values.

Additionally, a charge-coupled device was not used which would have allowed for a clear image of the cell sample to be obtained, so the observed trend between the degree of polarisation and the intensity of light from the LED had to be relied on to make a conclusion on the extent to which the sample could polarise light.

3.6 Future Work

This research can be further improved upon by using actual human cells to test in order to make the data more reliable and confirm that it could be a viable method of cancer detection. This is because no matter how much data was collected with model specimens, the data could not be as reliable as with real cancer cells. As such, partnering with medical professionals and researchers would allow for more applicable data to be collected.

4.0 Conclusion

The set-up was able to determine the extent to which a sample of cells polarised light, and hence also could determine the extent of healthy or unhealthy cells in a cell sample. There was a clear trend shown between the amount of healthy cells in the sample, or the amount of light polarised by the sample, and the resultant intensity of light from the LED. Using this set-up would very possibly increase the speed at which cancer cells in the body are detected by a large amount, and this would hence create a much more convenient method of cancer detection, even in the early stages.

Possible further work would include partnering with medical professionals and researchers, which would allow for testing with the device using actual human body cells, both healthy and unhealthy. This would help to identify a more accurate trend between the amount of unhealthy cells in a human cell sample and the amount of light polarised by it.

5.0 References

1. Kennerson, E. (2016, November 15). WATCH: Mantis Shrimp's Incredible Eyesight Yields Clues For Detecting Cancer. Retrieved from https://www.npr.org/sections/health-shots/2016/11/15/501443254/watch-mantis-shrimps-incredible-eyesight-yields-clues-for-detecting-cancer
2. Shrimp vision, communication and cancer detection. (2015, November 20). Retrieved from https://www.uq.edu.au/news/article/2015/11/shrimp-vision-communication-and-cancer-detection
3. Eldridge, L. (n.d.). Cancer Cells vs. Normal Cells: How Are They Different? Retrieved from https://www.verywellhealth.com/cancer-cells-vs-normal-cells-2248794
4. York, T., Powell, S. B., Gao, S., Kahan, L., Charanya, T., Saha, D., . . . Gruev, V. (2014, October). Bioinspired Polarization Imaging Sensors: From Circuits and Optics to Signal Processing Algorithms and Biomedical Applications: Analysis at the focal plane emulates nature's method in sensors to image and diagnose with polarized light. Retrieved from https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4629637/
5. Qi, J., & Elson, D. S. (2016, May 12). A high definition Mueller polarimetric endoscope for tissue characterisation. Retrieved from https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4865982/
6. Comunicación, B. (2016, May 31). Mantis shrimp, polarized light and cancer. Retrieved from http://atriainnovation.com/en/2630-2/
7. Szondy, D. (2014, October 02). Mantis shrimp's eyes inspire new cancer-detecting camera. Retrieved from https://newatlas.com/mantis-shrimp-eyes-cancer-camera/34049/
8. Bioinspired Polarization Imaging Sensors: From Circuits and Optics to Signal Processing Algorithms and Biomedical Applications. (n.d.). Retrieved from https://ieeexplore.ieee.org/document/6880796
9. Liu, Y., York, T., Akers, W. J., Sudlow, G. P., Gruev, V., & Achilefu, S. (n.d.). Complementary fluorescence-polarization microscopy using division-of-focal-plane polarization imaging sensor. Retrieved from

https://www.spiedigitallibrary.org/journals/journal-of-biomedical-optics/volume-17/issue-11/116001/Complementary-fluorescence-polarization-microscopy-using-division-of-focal-plane-polarization/10.1117/1.JBO.17.11.116001.full?SSO=1

10. Chang, J., He, H., Wang, Y., Huang, Y., Li, X., Chao, . . . Ma, H. (n.d.). Division of focal plane polarimeter-based 3 × 4 Mueller matrix microscope: A potential tool for quick diagnosis of human carcinoma tissues. Retrieved from https://www.spiedigitallibrary.org/journals/Journal-of-Biomedical-Optics/volume-21/issue-05/056002/Division-of-focal-plane-polarimeter-based-34-Mueller-matrix-microscope/10.1117/1.JBO.21.5.056002.full?SSO=1
11. Whiteman, H. (2017, September 08). Cancer detected in just 10 seconds with new device. Retrieved from https://www.medicalnewstoday.com/articles/319331.php
12. Nature's elegant and efficient vision systems can detect cancer. (2014, December 05). Retrieved from https://www.uq.edu.au/news/article/2014/09/natures-elegant-and-efficient-vision-systems-can-detect-cancer
13. Catalyst Home. (n.d.). Retrieved from http://www.abc.net.au/catalyst/stories/3280489.htm
14. Yong, E. (2008, March 21). Mantis shrimps have a unique way of seeing. Retrieved from https://www.nationalgeographic.com/science/phenomena/2008/03/21/mantis-shrimps-have-a-unique-way-of-seeing/
15. Yong, E. (2014, July 03). Nature's Most Amazing Eyes Just Got A Bit Weirder. Retrieved from https://www.nationalgeographic.com/science/phenomena/2014/07/03/natures-most-amazing-eyes-just-got-a-bit-weirder/
16. Extreme mobility of mantis shrimp eyes. (2018, May 02). Retrieved from https://www.sciencedaily.com/releases/2018/05/180501193534.htm
17. Land, M. (2008, April 22). Biological Optics: Circularly Polarised Crustaceans. Retrieved from https://www.cell.com/current-biology/fulltext/S0960-9822(08)00176-0#fig1

6.0 Acknowledgements

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Appendix

Angle / °	Average Intensity / lux
0	19933
5	13750
10	14950
15	14183
20	12933
25	11283
30	10567
35	9850
40	7933
45	7500
50	6683
55	5817
60	5483
65	3767
70	2483
75	1217
80	767
85	617
90	133
95	350
100	500
105	1317
110	1917
115	2383
120	3533
125	4567
130	5117
135	7267
140	6917
145	9017

150	9350
155	10250
160	11133
165	11917
170	12367
175	12000
180	13350

Angle of polariser / °	Intensity of LED 1 / lux	Intensity of LED 2 / lux	Intensity of LED 3 / lux	Average / lux
-90	8	9	9	8.7
-85	14	15	15	14.7
-80	20	20	24	21.3
-75	27	27	30	28
-70	33	32	35	33.3
-65	38	38	39	38.3
-60	42	42	41	41.7
-55	44	45	43	44
-50	46	46	43	45
-45	48	45	41	44.7
-40	43	43	39	41.7
-35	41	40	35	38.7
-30	35	35	28	32.7
-25	29	29	22	26.7
-20	23	21	16	20
-15	15	14	9	12.7
-10	6	7	3	5.3
-5	2	3	1	2
0	1	5	3	3
5	6	9	8	7.7
10	12	17	14	14.3
15	19	25	21	21.7
20	27	31	27	28.3

25	34	37	30	33.7
30	40	41	34	38.3
35	43	43	36	40.7
40	45	42	36	41
45	44	44	35	41
50	42	41	32	38.3
55	38	40	29	35.7
60	33	35	25	31
65	28	27	23	26
70	23	20	15	19.33333333
75	15	14	10	13
80	11	9	7	9
85	8	8	6	7.333333333
90	10	11	8	9.666666667