TO CONDUCT FOG LAMPS TESTING ON M1, RAVI INTERCHANGE, COLLECTING DATA AND DEDUCING RESULTS

A final year project report

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In Partial Fulfillment

of the Requirements for the Degree of

Bachelors of Mechanical Engineering

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ABSTRACT

The purpose of this project is to develop a thorough understanding and characterization of fog based on the following parameters, visibility range, forward backward scattering and density. A fog profile will be generated on the basis of these parameters at natural fog conditions. The experimentation site will be considered after through research and data analysis. The profiling of fog will be accompanied by the fog lamps testing provided to us by HELLA and solutions to the obscured vision will be based on those results. As for the second phase of this project, similar to natural fog conditions will be produced in laboratory settings and similar experimentation will be carried out but in detail, taking in account all the factors and variables which impart significant change in the fog conditions and effect the normal visibility range for drivers on road.

PREFACE

This report contains results and findings of Light Testing at motorway M1 and M2 at natural fog conditions. The project was undertaken by students of National University of Sciences & Technology and carried out with collaboration National Highway Authority of Pakistan. This report contains data, graphs and experimental readings that were taken during the course of this project.

ACKNOWLEDGMENTS

Firstly, all thanks and praises to Allah that we have completed this project successfully. We are really thankful to the each and every faculty member of SMME who provided us with the minor of details and were always there when we needed assistance. However, there are a few names as well as few departments that cannot be passed unsaid. Beginning with our core supervisor, Colonel Naveed Hassan, who was a constant source of motivation for us and guided us through each and every step of this project. Sir we are extremely thankful to you for being there for us whenever we needed you. The person who deserves an equal credit as our supervisor, Dr. Sami ur Rahman Shah. These both individuals were a great source of help, always available when we needed them and the projects they assigned us lead to the most versatile of experience we could have. The project assigned to us lead to some interactions with some really experienced people in the National Highway Department, one of them being Mr. Afzal (DSP Ravi Interchange), without their utmost guidance and collaboration this project would have not been completed. Not to forget Mr. Asad Malik from HELLA who provided answers to our query and guided us throughout the process. In the end we would like to pay our special regards to that one person who helped us in fabrication of our project and without whose supervision we believe this project had not been completed in mean time, that person is none other than Mr. Faisal Nadeem from DMRC. There was a very good learning environment. We will always remember their cooperation and support at our department. Lastly, we offer our regards and blessings to all of those who supported us in any respect during the completion of this project and our degree.

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Fog Lamps

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ABBREVIATIONS

HELLA	Hella KGaA Hueck & Co
NHA	National Highway Authority
NUST	National University of Sciences and Technology
M1	Motorway 1
SMME	School of Mechanical and Manufacturing Engineering
DMRC	Design and Manufacturing Resource Center

NOMENCLATURE

I	Rate of total radiation incident on the absorber‘s surface
A	Collector area
V	Velocity
Re	Reynolds Number
U	Viscosity
LUX	Unit for luminous flux of light

CHAPTER 1

INTRODUCTION

Fog is boundary layer phenomena whose formation is usually influenced by surface conditions. Fog is considered as serious hazard in Punjab and Sindh particularly during winter. Winter in Pakistan became short and intense under the changing climate. The maximum frequency of **dense fog** has been observed in **Sialkot, Lahore, Bahawalnagar, Faisalabad** and its adjoining areas while maximum frequency of **Moderate/Shallow** fog has been seen in **Multan & Sukkur**. The decadal analysis of surface visibility from 2001-2010 depicts fall in visibility up to 200m and on some occasions it reduces even up to 50m during dense fog period in upper Punjab.

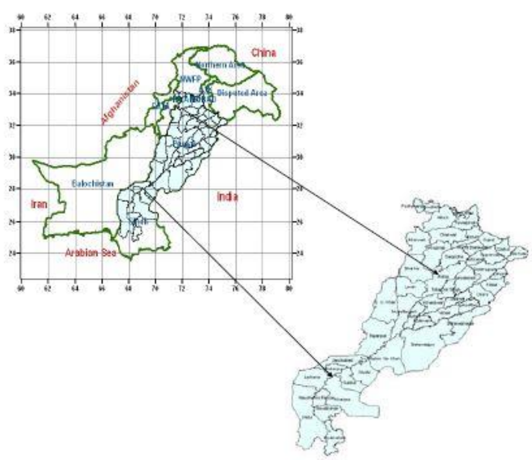


Figure 1: Fog prevalent areas in Pakistan

The average dry bulb temperature and relative humidity analysis reveals the fact that decrease in temperature and increase in relative humidity results in increasing frequency of foggy days in Punjab. Calm wind is observed during foggy conditions in Punjab.

In the recent times, a lot of accidents have been recorded due to fog and it has been a constant source of worry for the highway administration and government as there are

1000+ accidents each year in fog season. As a result of this large number of accidents, a project was launched by a German automotive lights manufacture company **Hella KGaA Hueck & Co.** This project was put in hands of students from **National University of Sciences and Technology, Islamabad**. This project is in collaboration with the **National Highway Authority (NHA)** under the faculty supervision of **Dr. Sami ur Rahman Shah** and **Col. Naweed Hasan**.

The vision behind this project is to find the root cause of these accidents due to fog, that either the alarming systems are not up to the mark or the fog lamps currently being employed are not good enough in the given fog condition

It should be noted the lights provided by HELLA are of international standard and currently being used in state of art automobiles. Therefore it provided us an ample comparison of lights currently being employed in our cars, most of them being halogen lights (yellow lights) or HID's, and the international standards.

The design of experiment, methodology, application and the industrial linkage will be discussed later in this report. A step by step approach will be accounted starting from the concept phase to procurement and design of experiment, till a conclusion and validation of results.

Table 1: Fog by distance

Fog Type	**Visibility Range (m)**
Shallow	500- 999
Moderate	200- 500
Dense	50- 200
Very Dense	< 50

CHAPTER 2

LITERATURE REVIEW

Types of fog in Pakistan

Fog is a meteorological phenomenon in which a cloud (stratus) which has its base on or close to ground level and visibility reduces to < 1000 meters.

Fog formation can occur in two ways. First, the air is cooled to the dew point which leads to the formation of **fog** droplets. When the sun rises, the air and ground warm up. This leads to the air temperature being warmer than the dew point temperature, which **causes** the **fog** droplets to evaporate. We'll be discussing the two important and prevalent fog types in the study area of our project.

Advection fog

Advection fog forms due to moist air moving over a colder surface, and the resulting cooling of the near-surface air to below its dew-point temperature. Advection fog occurs over both water (e.g., steam fog) and land.

Radiation fog

Radiation cooling produces this type of fog. Under stable nighttime conditions, long-wave radiation is emitted by the ground; this cools the ground, which causes a temperature inversion. In turn, moist air near the ground cools to its dew point. Depending upon ground moisture content, moisture may evaporate into the air, raising the dew point of this stable layer, accelerating radiation fog formation.

The **radiation fog** is the most dominant type of fog. The favorable conditions for its development are **light wind, clear sky, high moisture and lack of turbulence**. The soil conditions like soil moisture and vegetation cover influence the soil thermal conductivity which plays a vital role in formation of radiation fog.

Effect of Aerosols

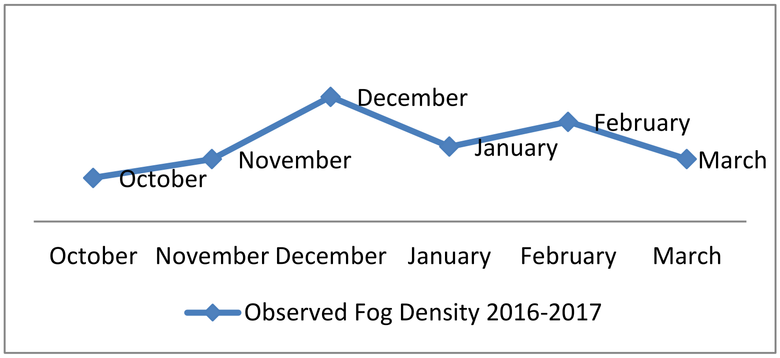
Fog also forms in the environment, where there are large concentrations of aerosols characterized by a low activation super saturation. The high aerosols loads are an important factor contributing in severity of fog events. The enhanced pollution load result in atmospheric reactions, producing the secondary pollutants that may lead to increased aerosol concentration in the atmosphere. This could cause enhanced water aerosol in the presence of favorable meteorological conditions and high relative humidity.

Fog is also termed as forward scattered or backward scattered, depending on the droplet size. In advection fog there is more scattering as compared to radiation fog and in most of the cases forward scattering is employed.

Timeline of Fog in Pakistan

Fog usually forms during November to February in Pakistan. Most of the studies made Punjab as a focal point for fog formation. It should be accounted that dense fog in Pakistan appears in two phases, the first phase during the midst of November to end of December while the second phase being comparatively shorter than the prior one, spanning over the month of February. In the months of October and January there is fog but depends, it can be displacement fog and patchy i.e. it will be moving from places to places, you'll find maximum fog at one location and just a few kilometers apart there'll be clear sky.

Table 2: Timeline of fog in Pakistan



The Beer-Lambert Law

The Beer- Lambert Law states that light is attenuated in a logarithmic manner. Whenever there is approximately 10 times depreciation in the lux being received at the other end, the viewer will observe a half decrement in the visibility of light. The Beer- Lambert Law is further explained as:

Consider a beam of light on a material

- It can be scattered, absorbed or transmitted

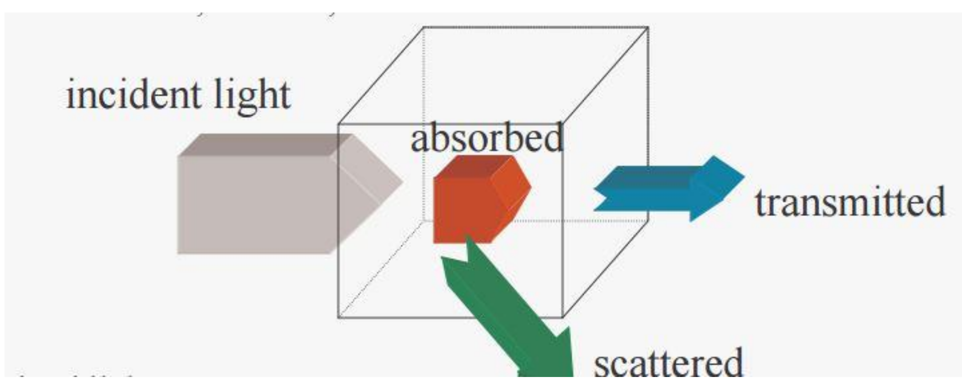


Figure 2: The Beer Lambert Law

- Transmitted light

  The light emerges propagating in the same direction as the incident light.

- Absorbed light

Energy from the light is absorbed in the volume of the material

- Scattered light

  Light emerges in a different direction from the incident light

Now, consider a light incident on a material with area A and thickness dx and concentration of molecules C. (i.e # of molecules / cm3). Number of molecules illuminated by light of incident intensity Ix is CAdx. The probability of light being scattered out of the beam in the thickness dx is:

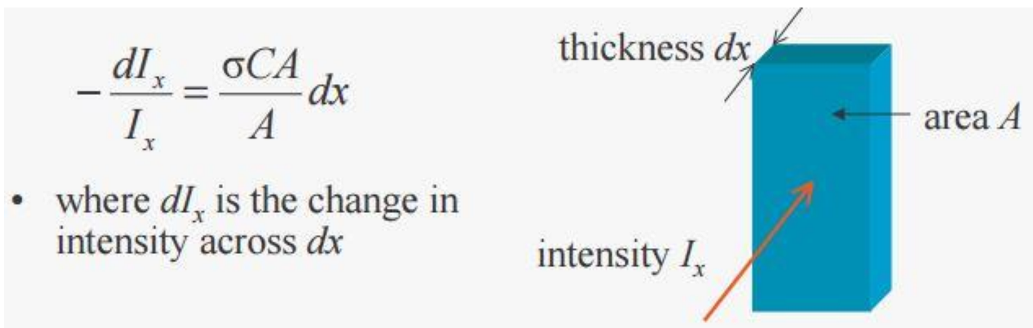


Figure 3: The Beer Lambert Law explained

Where,

$$Transmittance = \frac{I(\lambda)}{I_0\ (\lambda)} \qquad \text{(Eq. 1)}$$

And,

$$I = I_0 e^{-\sigma Cx} = I_0 ee^{-\mu x} \qquad \text{(Eq. 2)}$$

CHAPTER 3

METHODOLOGY

Design of Apparatus

Headlights have the basic purpose of providing visibility to driver. Under normal conditions, halogen bulb, usually used in headlights provides enough visibility to the driver. But under specific conditions like fog or mist, these halogen headlights are compromised. So instead of halogen light, fog lights, HIDs or some other lights are more reliable. Our main purpose is to measure the visibility provided by various headlights.

Our experiment basically involves testing of various lights like local fog lights, halogen lights and lights from HELLA, under different fog conditions on the field. Experiment is performed on motorway. Mandatory permissions for testing on motorway and other formalities were completed before experimentation.

Design of Experiment

After a detailed literature review on fog formation and its types the next step was to propose a suitable design of experiment. For this we took the help of our supervisors who gave us an easy approach to our experiment and divided the project in following basic steps:

1. Take in account all the atmospheric conditions, dry bulb temperature, relative humidity, wet bulb temperature and wind speed, visibility range, to develop a understanding on the type of fog and its density.
2. Manufacture an assembly consisting of two stands that can vary in height from 1m to 5m with the help of a telescopic arrangement.
3. These stands will be placed at different distances apart such as 5m, 10m, 20m, 30m, 40m, and 50m and so on to 100m.
4. One stand will be mounted with the light stand holding the different lights. The other will be mounted with a Lux meter at same height.

5. Take readings on how many lumen/meter sq. are being captured from the respective light at that particular distance.
6. Compare these readings to that of taken on a clear day.
7. Plot a graph and generate a profile on the visibility of each light.

Light measurement experiment will be as follows:

Table 3: Design of Experiment

Serial #	Light #	Experiment	Height	Distance
1	1	Direct light measurement	1ft, 1,2,3,4,5m	5,10,20,30,40,50,60m
2	2	Direct light measurement	1ft, 1,2,3,4,5m	5,10,20,30,40,50,60m
3	3	Direct light measurement	1ft, 1,2,3,4,5m	5,10,20,30,40,50,60m
4	4	Direct light measurement	1ft, 1,2,3,4,5m	5,10,20,30,40,50,60m
5	5	Direct light measurement	1ft, 1,2,3,4,5m	5,10,20,30,40,50,60m
6	6	Direct light measurement	1ft, 1,2,3,4,5m	5,10,20,30,40,50,60m

Experiment Assembly

Our experiment consists of an emitter assembly and a receiver assembly. Headlights are installed on the emitter assembly. Emitter assembly has a variable height (form 1 ft. to 5 meter) in order to test the headlights on various heights. Receiver assembly has a LUX meter at its top. Its height is also variable and is adjusted according to the height of headlight. Receiver assembly can also be equipped with a reflector plate. Reflector plate has the purpose of reflecting the light form headlight so that its reflected effect can be measured.

- Height of stands: Min 1m, Max 5m
- Three pipe given a telescopic arrangement.
    - Pipe Gauge: 16
    - Pipe Diameter: 55mm, 75mm and 90mm
    - Pipe Material: Mild Steel
- Brushes made of M8 Bolts used to help the telescopic arrangement.
- Caster wheels used for mobility of assembly.
- Angle iron 1.5" used for the clamping of lights.
- Two O rings used machined from aluminum to clamp the light stand on top.
- Lights mounted: Total Lights are 6 (2 German, 4 Local)
- Battery used: Two 12V batteries. Inverter used for charging.
- Generator used as backup charging.
- Auto wires of 16 to 18 conductance used.

Table 4: Lights nomenclature

Light no.	Type
1	**Halogen Lamps**
2	**Toyota Fog Lamps**
3	**Nissan Fog Lamps**
4	**HELLA LED**
5	**HELLA Fog light 2 (24v)**
6	**Pencil Beam Spotlight**

Figure 4: Assembly in manufacturing phase

Equations and Graphs of Lights at vertical height of 1m over the horizontal Range without Fog at SMME, NUST, Islamabad

This is the post analysis of the experimental data including the data point's graphs from the points, governing equations are derived from the MATLAB code and then the equation graph is plotted and for checking the accuracy of the equation derived a comparison graph is plotted. There is very slight difference between the equation graph and data graph

.

Table 5: Zero fog experiment

Location	SMME NUST ISLAMABAD
Date	16 January 2017
Time	9 pm to 12 am
Fog condition	Zero Fog
Temperature	5.2^o C
Relative Humidity	87%

Light 1

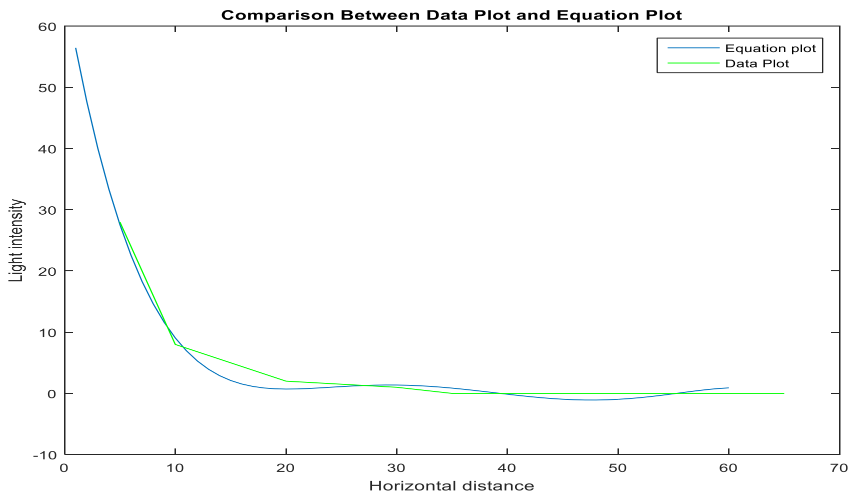
Data Points

x1=[5 10 20 30 35 40 50 60 65];

y1=[28 8 2 1 0 0 0 0 0];

Governing Equation

eq = -1.233e-06 s^5 + 0.0002432 s^4 – 0.01817 s^3 + 0.6381 s^2 – 10.53 s + 66.37



Equation 1: Comparison between data plot and equation plot for light 1 in zero fog

Light no. 2

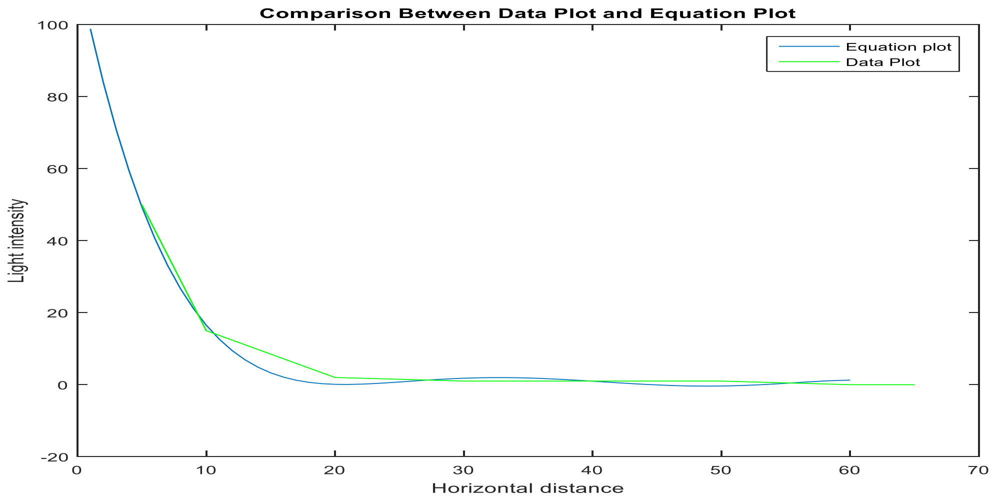
Data Points

x1=[5 10 20 30 35 40 50 60 65];

y1=[50 15 2 1 1 1 1 0 0]

Governing Equation

eq =-1.764e-06 s^5 + 0.0003589 s^4 - 0.02787 s^3 + 1.024 s^2 - 17.7 s + 115.5



Equation 2 Comparison between data plot and equation plot for light 2 in zero fog

Light no. 3

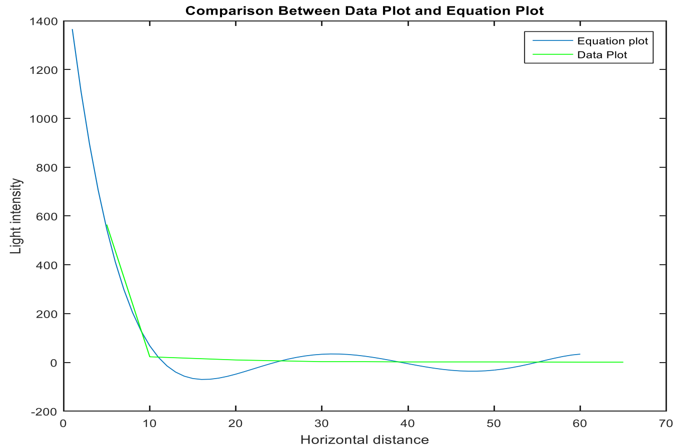
Data points

x1=[5 10 20 30 35 40 50 60 65];

y1=[565 23 10 3 3 2 2 1 1];

Governing equation

eq =-4.205e-05 s^5 + 0.008186 s^4 - 0.5983 s^3 + 20.2 s^2 - 308.7 s + 1655



Equation 3 Comparison between data plot and equation plot for light 3 in zero fog

Light no. 4

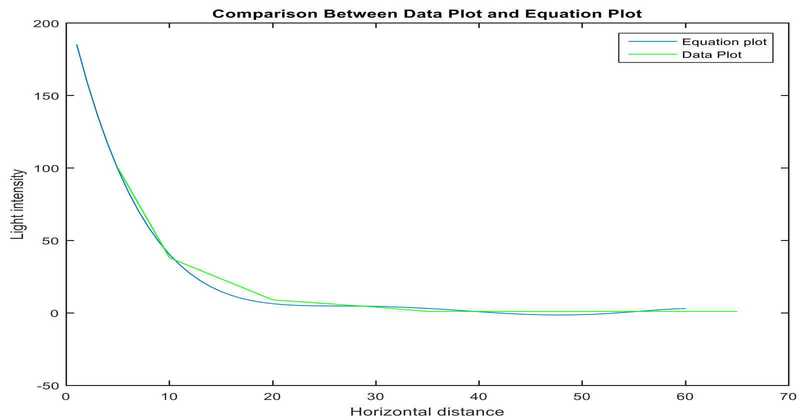
Data points

x1=[5 10 20 30 35 40 50 60 65];

y1=[100 38 9 4 1 1 1 1 1];

Governing Equation

eq = -3.045e-06 s^5 + 0.000613 s^4 - 0.04716 s^3 + 1.732 s^2 - 30.58 s + 214.2



Equation 4: Comparison between data plot and equation plot for light 4 in zero fog

Light no. 5

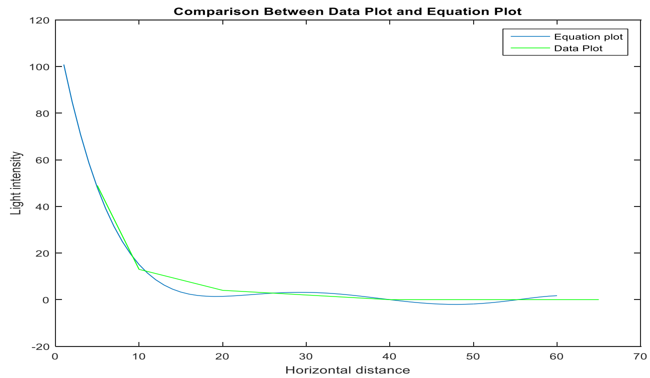
Data points

x1=[5 10 20 30 35 40 50 60 65];

y1=[49 13 4 2 1 0 0 0 0];

Governing Equation

eq =-2.363e-06 s^5 + 0.0004642 s^4 - 0.03443 s^3 + 1.195 s^2 - 19.34 s + 119



Equation 5: Comparison between data plot and equation plot for light 5 in zero fog

Light no. 6

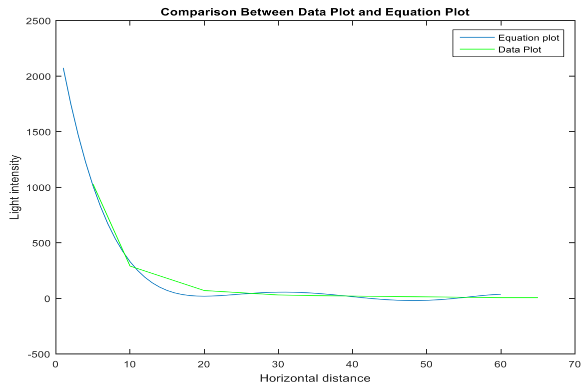
Data points

x1=[5 10 20 30 35 40 50 60 65];

y1=[1030 290 70 30 24 20 13 6 6];

Governing Equation

eq =-4.283e-05 s^5 + 0.008544 s^4 - 0.6468 s^3 + 23.04 s^2 - 384.3 s + 2435



Equation 6: Comparison between data plot and equation plot for light 6 in zero fog

Second Experiment at Faizpur Interchange, KSK

Table 6: Second Experiment at Faizpur Interchange, KSK

Experiment no. 1		
Date	18 January, 2017	
Parameters	**Start**	**End**
Time	12:00 AM	5:30 AM
Temperature	7.4 C	6.6 C
Relative Humidity	99%	99%
Fog Conditions	Shallow	Dense

Table 7: Light 2 readings

Light no. 2	Horizontal Distance						
Vertical Distance	**5**	**10**	**20**	**30**	**40**	**50**	**60**
1m	38	16	4	1	0.4	0.4	0
2m	43	16	6	1.7	0.8	0.5	0
3m	55	21	7	1.9	1	0.5	0
4m	52	27	7.4	2.1	2	0.5	0
5m	53	27	7.8	3	2	1	1

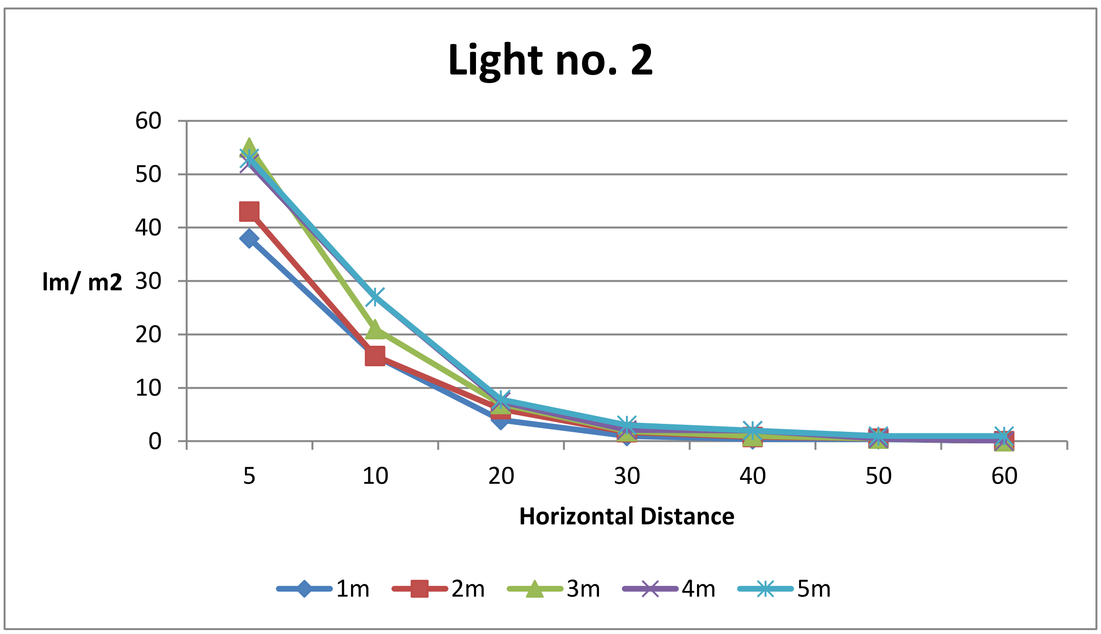


Figure 5: Light 2 readings

Table 8: Light 3 raeding

Light no. 3	Horizontal Distance						
Vertical Distance	**5**	**10**	**20**	**30**	**40**	**50**	**60**
1m	73	25	6	2	0.9	0.7	0.6
2m	87	27	7	2.5	1.1	0.7	0
3m	97	33	9	2.7	1.3	0.6	0
4m	95	35	10.7	3	1	0.6	0
5m	91	33	12	3.5	1	0.6	0

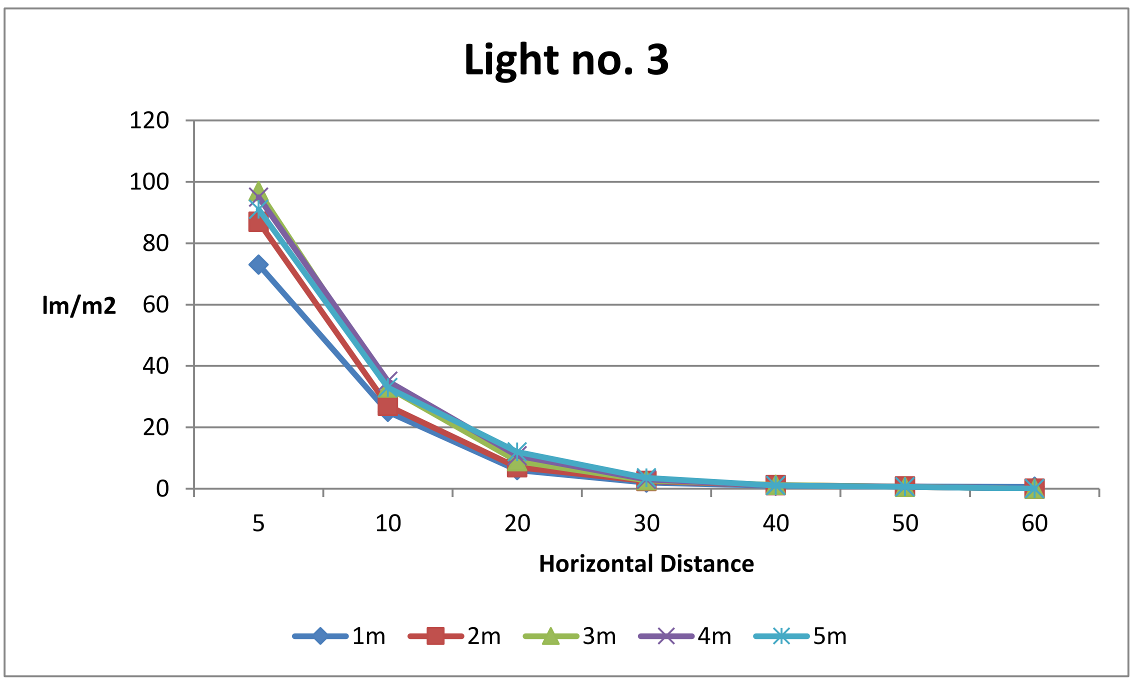


Figure 6: Light 3 readings

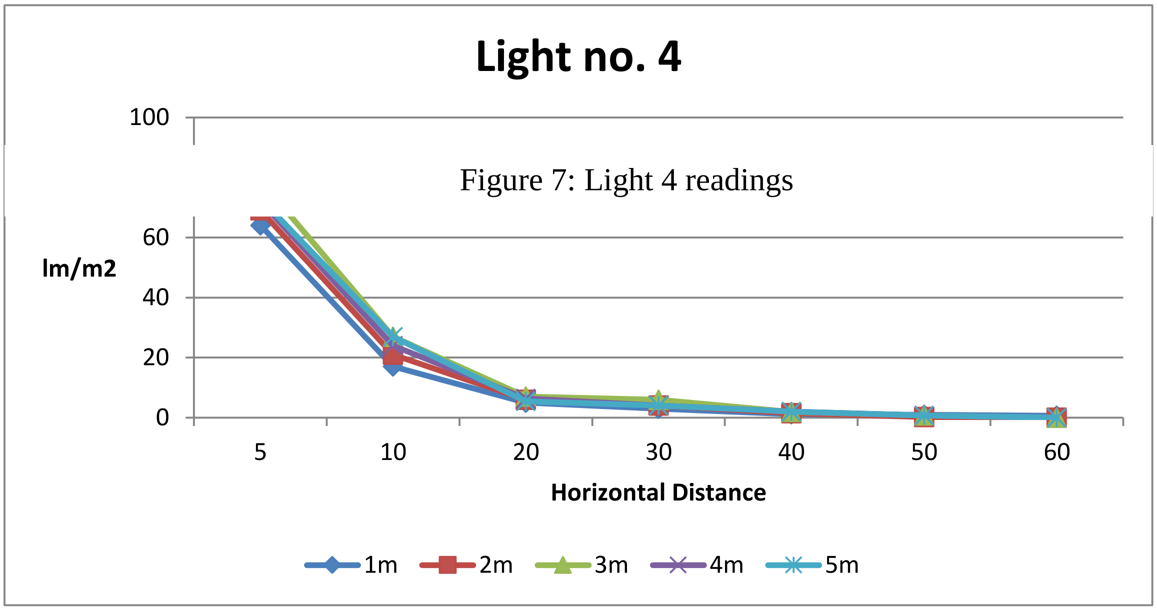


Figure 7: Light 4 readings

Light no. 4	**Horizontal Distance**						
Vertical Distance	**5**	**10**	**20**	**30**	**40**	**50**	**60**
1m	64	17	5	3	1.2	0.9	0.6
2m	69	21	6	4	1.5	0.2	0
3m	79	27	7	6	1.9	0.7	0
4m	72	24	6.4	4	2	0.7	0
5m	73	27	5.4	4	2	0.7	0

Table 9: Light 5 readings

	Horizontal Distance						
Vertical Distance	**5**	**10**	**20**	**30**	**40**	**50**	**60**
1m	48	13	3	2	0.8	0.5	0.3
2m	55	17	5	2.7	1.2	0.1	0
3m	82	23	5.9	4.6	1.7	0.5	0
4m	78	19	5.2	3.1	2	0.5	0
5m	82	20	4.2	1.5	2	0.5	0

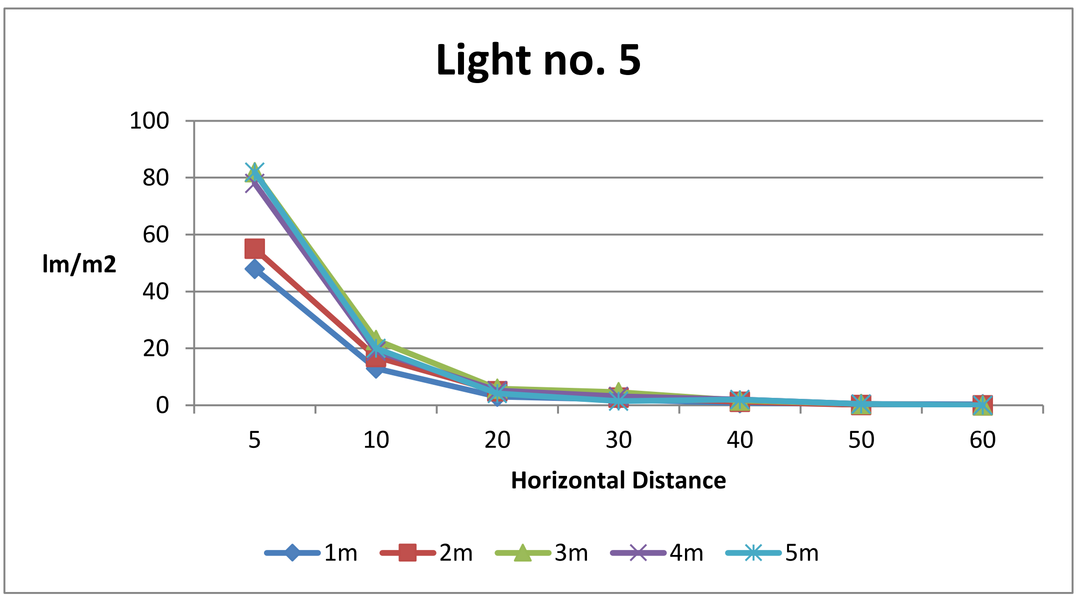


Figure 8: Light 5 readings

Table 10: Light 6 readings

Light no. 6	**Horizontal Distance**						
Vertical Distance	**5**	**10**	**20**	**30**	**40**	**50**	**60**
1m	1110	325	75	32	13.7	8.7	6.8
2m	1258	425	105	65	21	7.9	2
3m	1350	755	139	72	25	7.9	3
4m	1358	730	145	87	33	7.9	4
5m	1345	750	166	50	40	7.9	4

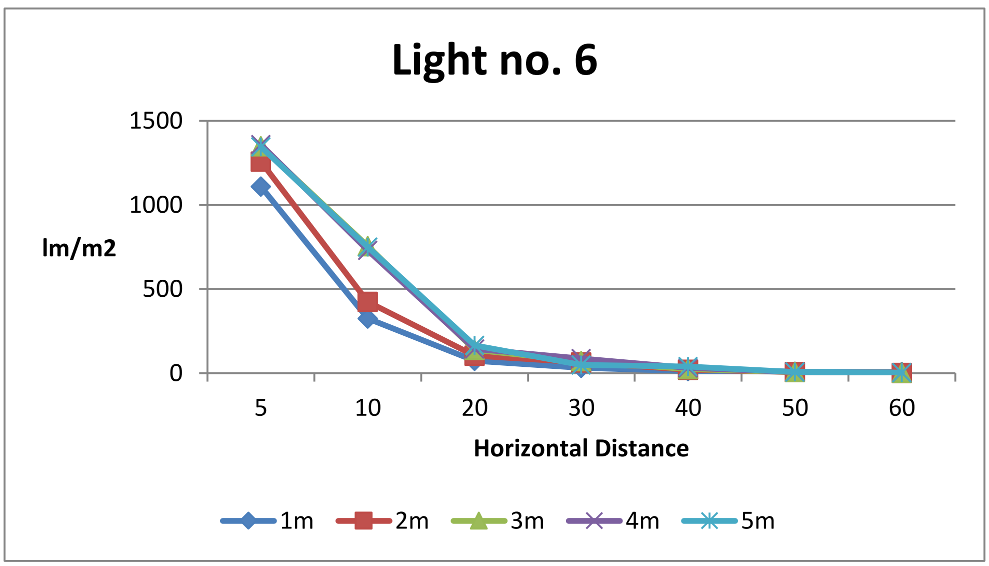


Figure 9: Light 6 readings

Third Experiment near Ravi Toll Plaza, Lahore

Table 11: Experiment at Ravi Toll Plaza

Experiment no. 2		
Date	31 January, 2017	
Parameters	**Start**	**End**
Time	1:00 AM	6:00 AM
Temperature	5.5 C	5.0 C
Relative Humidity	99%	99%
Fog Conditions	Very Dense	Very Dense

Table 12: Luminance readings for experimet no.2

Light no. 1	**Horizontal Distance**						
Vertical Distance	**5**	**10**	**20**	**30**	**40**	**50**	**60**
1ft	23	10	2	1	0	0	0
1m	25	11	3	1	0	0	0
2m	28	12	4	1	0	0	0
3m	30	14	5	1	0	0	0
4m	34	16	5	1	0	0	0
5m	38	19	7	2	0	0	0

Light no. 2	**Horizontal Distance**						
Vertical Distance	**5**	**10**	**20**	**30**	**40**	**50**	**60**
1ft	21	3	1	0	0	0	0
1m	24	3	1	0	0	0	0
2m	25	3.5	1	0	0	0	0
3m	26	5	2	0	0	0	0
4m	28	8	2	0	0	0	0
5m	31	10	2	0	0	0	0

Light no. 3	**Horizontal Distance**						
Vertical Distance	**5**	**10**	**20**	**30**	**40**	**50**	**60**
1ft	35	7	2	1	0	0	0
1m	36	8	2	1	0	0	0
2m	38	10	2	1	0	0	0
3m	38	11	2	1	0	0	0
4m	41	13	3	1	0	0	0
5m	46	14	4	3	0	0	0

Light no. 4	**Horizontal Distance**						
Vertical Distance	**5**	**10**	**20**	**30**	**40**	**50**	**60**
1ft	54	10	3	2	1	0	0
1m	58	11	4	2	1	0	0
2m	59	12.5	4	2	1	0	0
3m	60	15	5	2	1	0	0
4m	64	19	5	2	1	1	0
5m	65	24	8	5	2	1	0

Light no. 5	**Horizontal Distance**						
Vertical Distance	**5**	**10**	**20**	**30**	**40**	**50**	**60**
1ft	36	7	2	1	1	0	0
1m	38	7	2	1	1	0	0
2m	40	7	2	1	1	0	0
3m	42	9	2	1	1	0	0
4m	44	11	4	1	1	0	0
5m	44	15	5	2	1	0	0

Light no. 6	**Horizontal Distance**						
Vertical Distance	**5**	**10**	**20**	**30**	**40**	**50**	**60**
1ft	839	204	13	9	3	1	1
1m	858	216	16	10	3	1	1
2m	886	220	18	10	4	2	1
3m	898	233	20	13	5	3	1
4m	905	251	23	14	6	3	1
5m	913	259	26	15	6	3.5	2

Figure 10: Group photo with motorway officials

Comparison of Lights

The following charts show the difference in Lux each light gives at different distances. It is quite clear that light 6 has the most range and intensity.

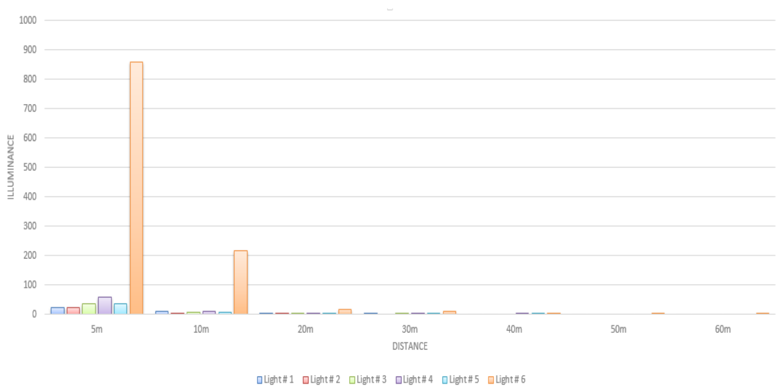


Figure 11: Comparispon of all 6 lights

Visual Conclusion

From a sample size of 4 students the visual results that we received on motorway were that the LED light provided by HELLA which was of 12 V and 16 W power rating was the most visually dependent light though it had very less intensity rating as compared to other lights but why was it so? The answer to this question will be covered in the second phase of this project which was the testing of these fog lamps in a controlled lab environment.

Key Points

It should be noted that the fog conditions at site of experiment were not steady and dense packets of fog flowed through the surface of road time to time. It would be clear sky at one time and the next moment there would be dense fog blocking the vision and leaving little lumens to be received at the other end. Therefore, there might be some fluctuation in the readings.

Equations and Graphs of Lights at vertical height of 1m over the horizontal Range in Fog at Ravi Interchange, KSK

Halogen Light

Data

This is the data collected by setting the vertical height of the halogen light to 1m and changing the horizontal distance from 0m to 60m and light intensity values are collected**.**

Horizontal distance x1=[5 10 20 30 40 50 60];

Light intensity y1=[119 52 10 5 3 1 1];

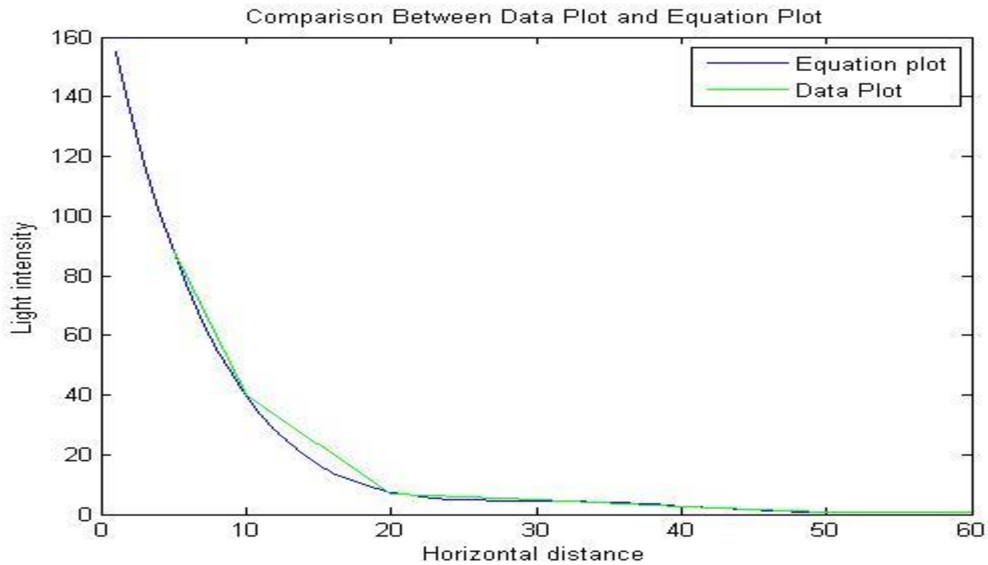
Governing equation

This is governing equation of the collected data derived from the matlab.in this equation the independent variable is (s) distance and the dependent variable is intensity which is shown as F(s).

F(s)= -1.811e-006 s^5 + 0.0003807 s^4 - 0.03096 s^3 + 1.215 s^2 - 23.17 s + 177.2

Comparison

Table 13: Comparison plot of Halogen lamp



Nissan Light

Data

This is the data collected by setting the vertical height of the Nissan light to 1m and changing the horizontal distance from 0m to 60m and light intensity values are collected**.**

Horizontal distance x1= [5 10 20 30 40 50 60];

Light intensity y1= [38 16 4 1 0.4 0.4 0.4];

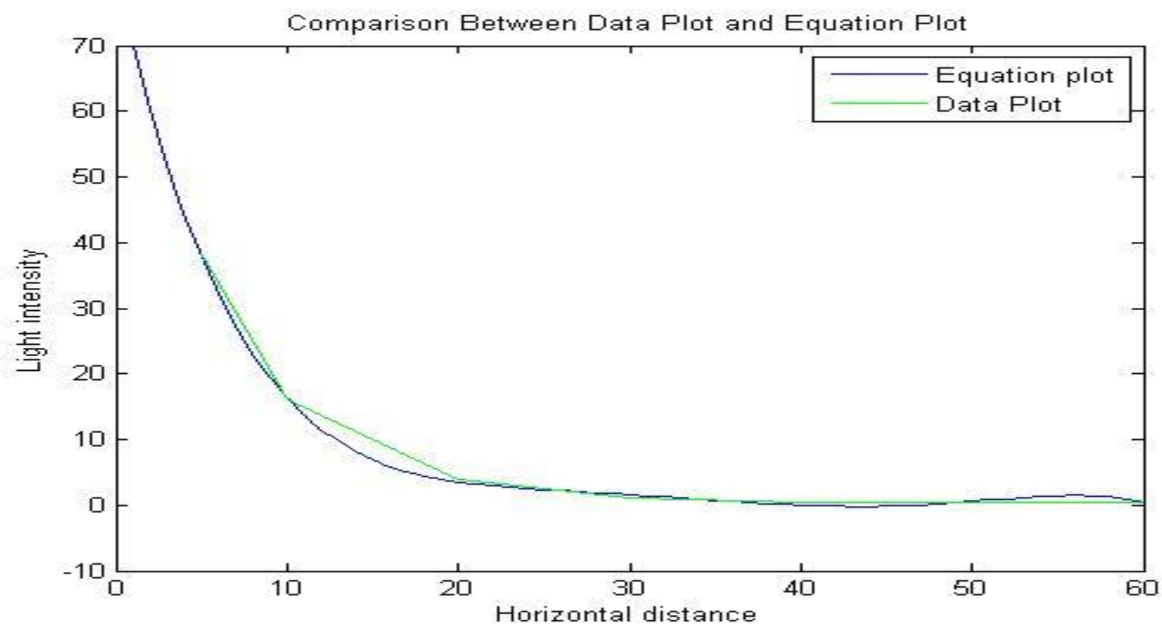
Governing Equation

This is governing equation of the collected data derived from the matlab.in this equation the independent variable is (s) distance and the dependent variable is intensity which is shown as F(s).

F(s) = -1.465e-006 s^5 + 0.0002723 s^4 - 0.01948 s^3 + 0.6744 s^2 - 11.51 s + 80.83

Comparison

Table 14: Comparison plot of Nissan Light



Toyota Light

Data

This is the data collected by setting the vertical height of the Toyota light to 1m and changing the horizontal distance from 0m to 60m and light intensity values are collected**.**

Horizontal distance x1=[5 10 20 30 40 50 60];

Light intensity y1=[73 25 6 2 0.9 0.7 0.6];

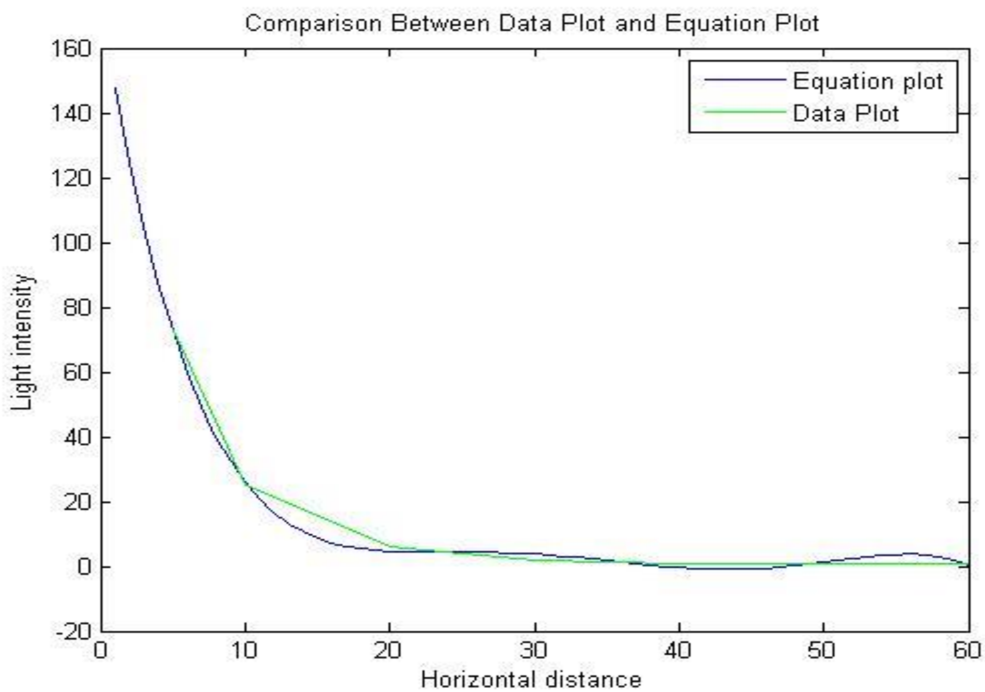
Governing Equation

This is governing equation of the collected data derived from the matlab.in this equation the independent variable is (s) distance and the dependent variable is intensity which is shown as F(s).

$F(s)= -4.105e-006\ s^5 + 0.0007517\ s^4 - 0.05244\ s^3 + 1.739\ s^2 - 27.61\ s + 173.3$

Comparison

Table 15: Comparison plot of Toyota Lamps



Hella LED

Data

This is the data collected by setting the vertical height of the Hella Led light to 1m and changing the horizontal distance from 0m to 60m and light intensity values are collected.

Horizontal distance x1=[5 10 20 30 40 50 60];

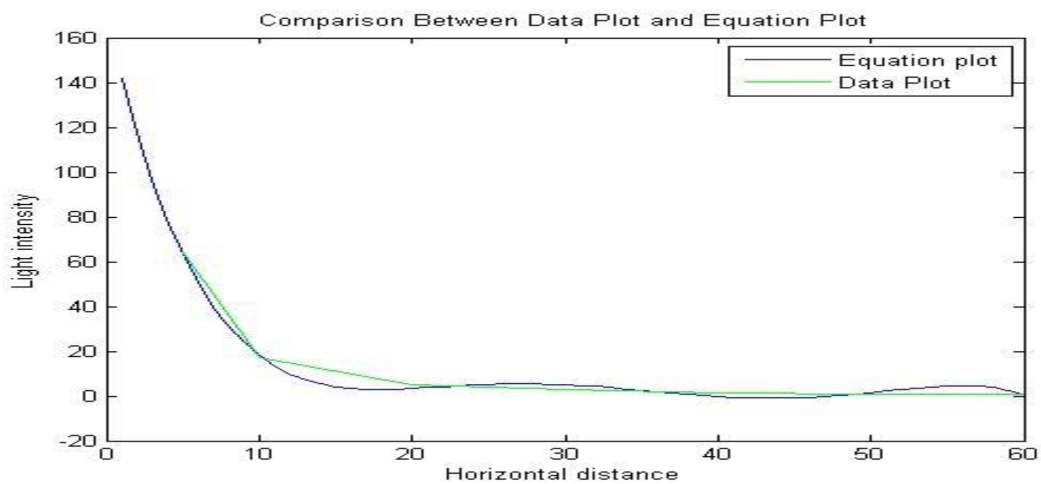
Light intensity y1=[64 17 5 3 1.2 0.9 0.6];

Governing Equation

This is governing equation of the collected data derived from the matlab.in this equation the independent variable is (s) distance and the dependent variable is intensity which is shown as F(s).

$$F(s)= -5.022e-006\ s^5 + 0.0009073\ s^4 - 0.06195\ s^3 + 1.983\ s^2 - 29.63\ s + 169.4$$

Table 16: Comparison plot of HELLA LED



Hella 2 Incandescent

Data

This is the data collected by setting the vertical height of the hella 2 light to 1m and changing the horizontal distance from 0m to 60m and light intensity values are collected**.**

Horizontal distance x1=[5 10 20 30 40 50 60];

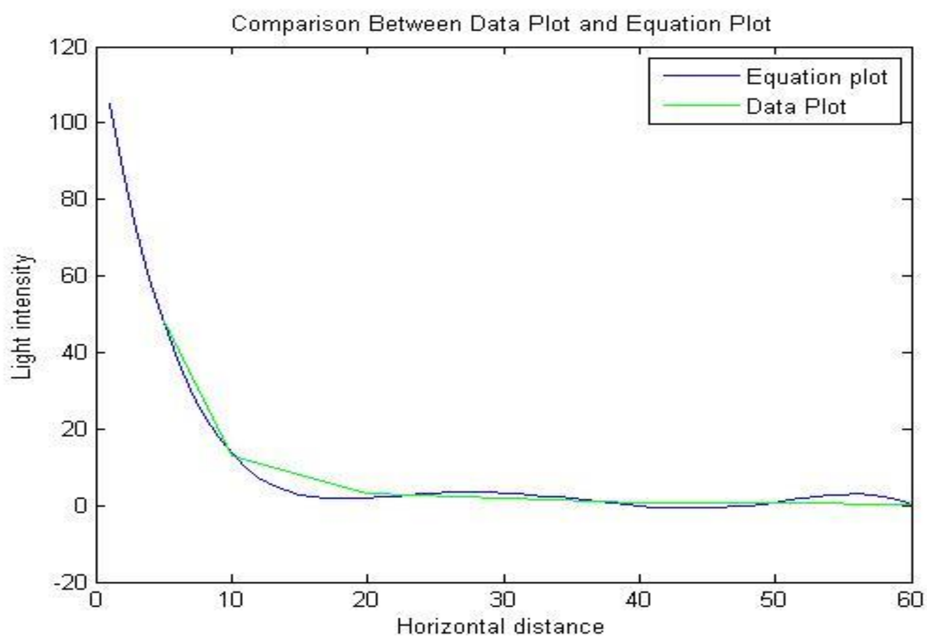
Light intensity y1=[48 13 3 2 0.8 0.5 0.3];

Governing Equation

This is governing equation of the collected data derived from the matlab.in this equation the independent variable is (s) distance and the dependent variable is intensity which is shown as F(s).

F(s)= -3.515e-006 s^5 + 0.0006398 s^4 - 0.04411 s^3 + 1.429 s^2 - 21.67 s + 125.5

Table 17: Comparison plot of HELLA Incandescent



Spot light

Data

This is the data collected by setting the vertical height of the halogen light to 1m and changing the horizontal distance from 0m to 60m and light intensity values are collected**.**

Horizontal data x1=[5 10 20 30 40 50 60];

Light intensity y1=[1110 325 75 32 13.7 8.7 6.8];

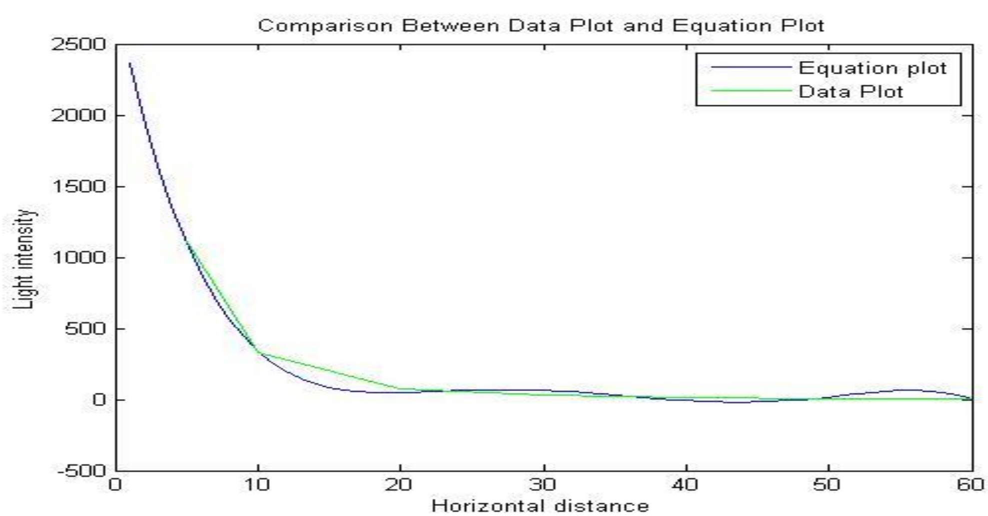
Governing Equation

This is governing equation of the collected data derived from the matlab.in this equation the independent variable is (s) distance and the dependent variable is intensity which is shown as F(s).

F(s)= -7.501e-005 s^5 + 0.01366 s^4 - 0.9442 s^3 + 30.78 s^2 - 473.3 s + 2811

Comparison

Table 18: Comparison plot of spot light



Light Contours

These are the contours of lights over the vertical range of 5m and the horizontal range of the 60m.this is the comparison of the lights between the behavior of the lights in the moderate fog on the first experiment no 1 and the behavior of the lights in the dense fog on the experiment no 2.

Halogen Light

This is the 2-dimensional contour of the light intensity varying both x and y coordinates which are position of observer and position of light respectively. While the color show the intensity of light.

This is the contour graph by the linear interpolation method.

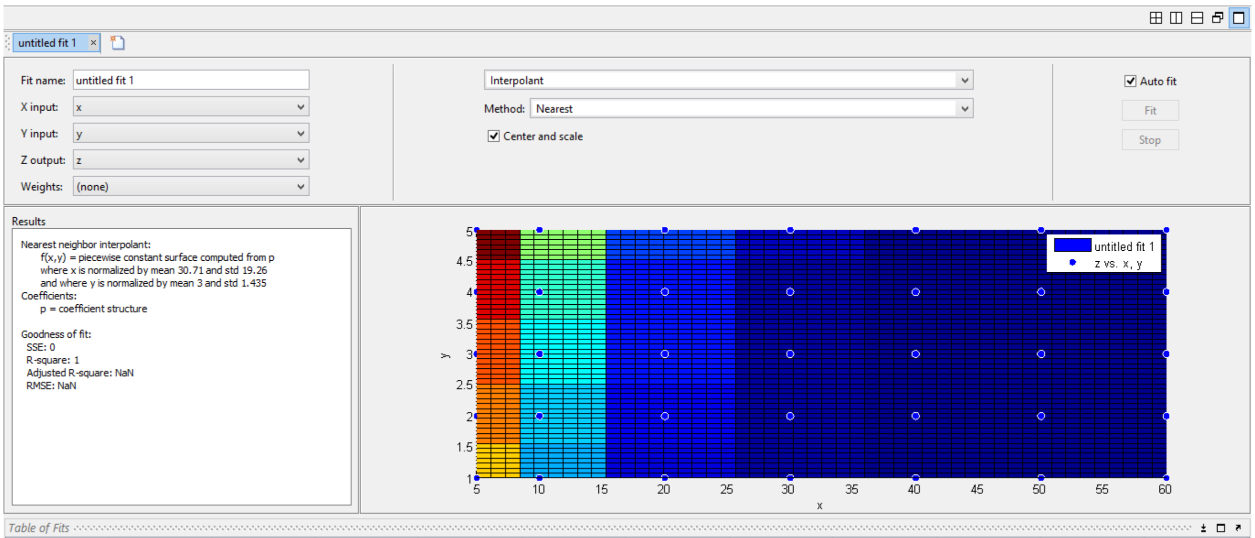


Figure 12: Contour 1 for halogen light

This is the contour graph by the nearest interpolation method.

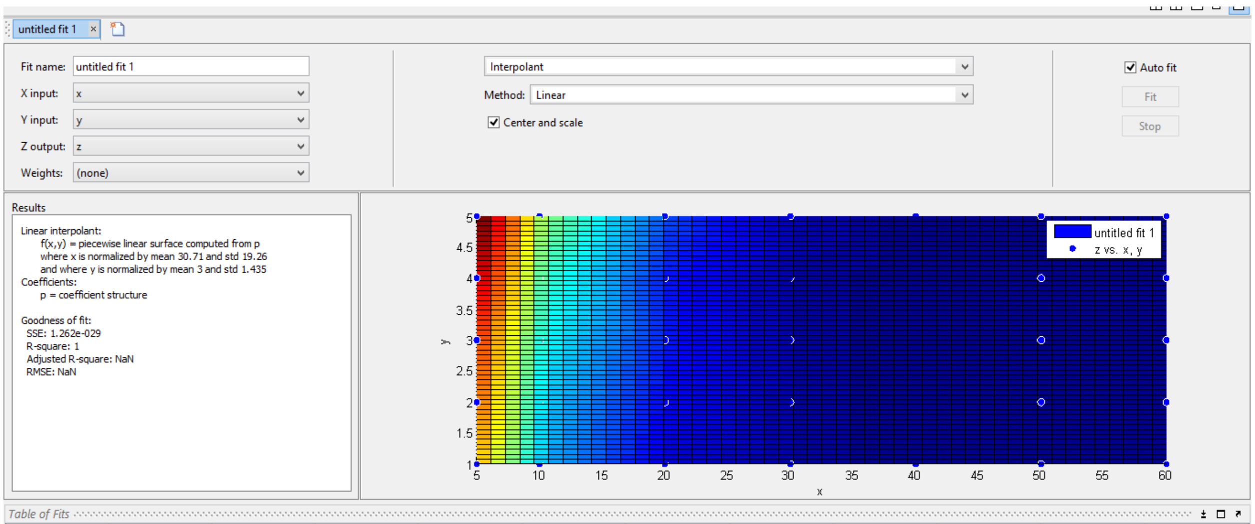


Figure 13: Contour 2 for halogen light

This is the contour graph by the polynomial interpolation method of degree one.

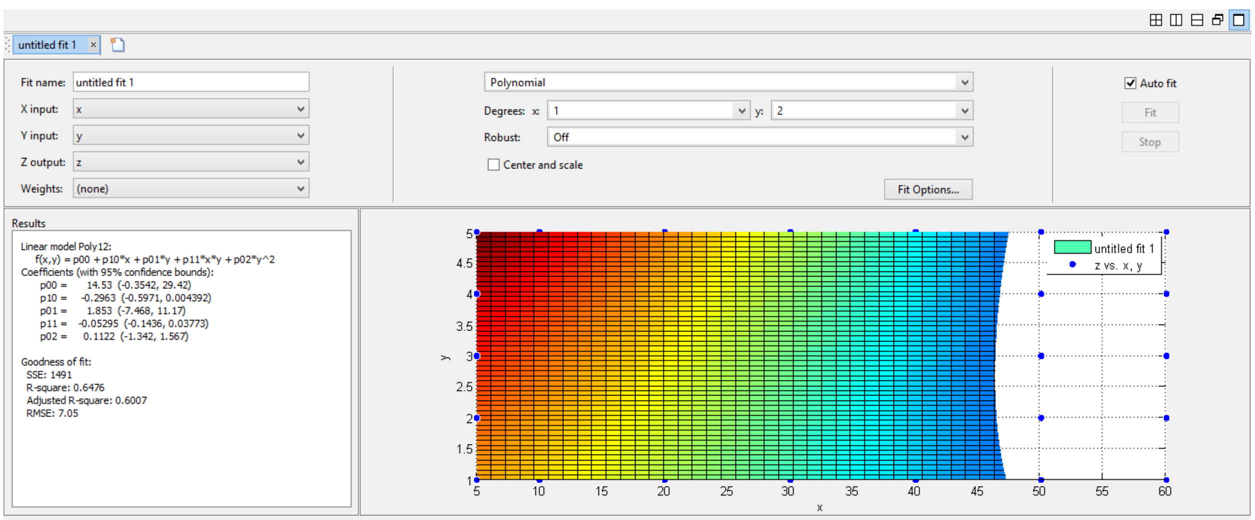


Figure 14: Contour 3 for halogen light

Toyota light

This is the 2-dimensional contour of the light intensity varying both x and y coordinates which are position of observer and position of light respectively. While the color show the intensity of light.

This is the contour graph by the linear interpolation method.

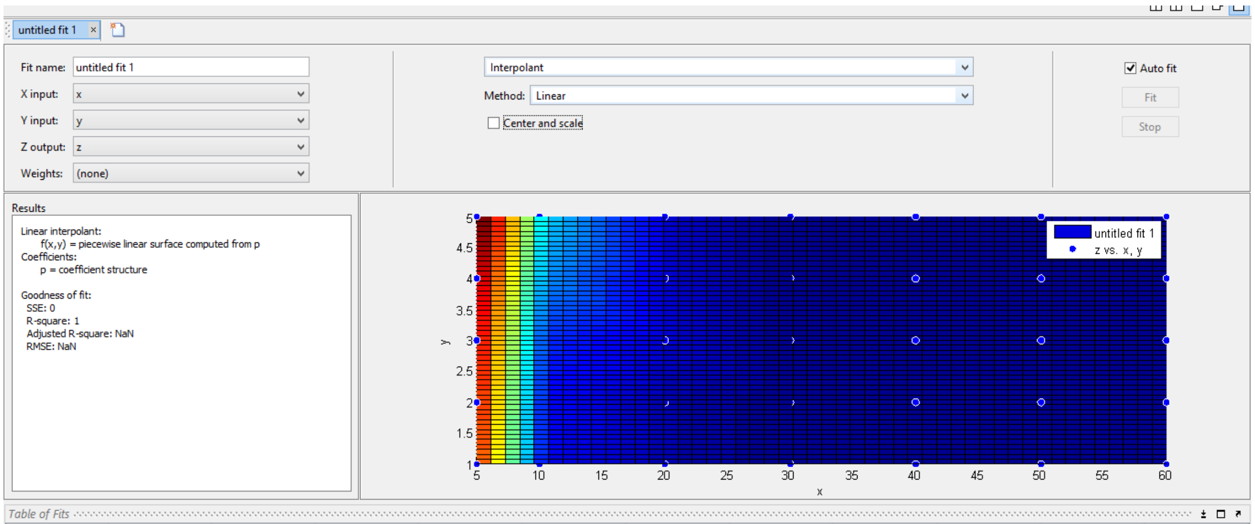


Figure 15: Contour 1 for toyota light

This is the contour graph by the nearest interpolation method.

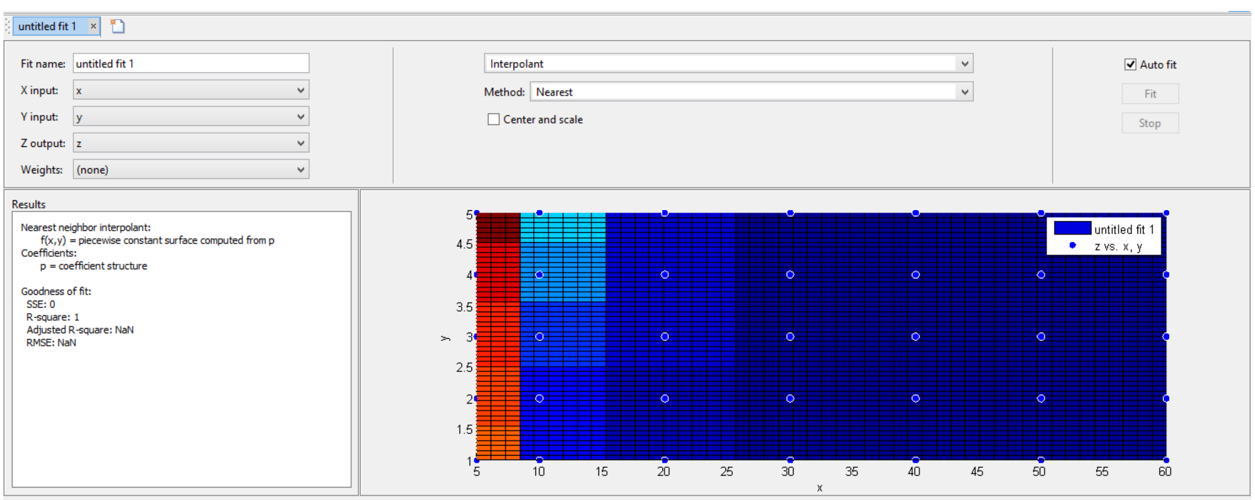


Figure 16: Contour 2 for toyota light

This is the contour graph by the polynomial interpolation method of degree one.

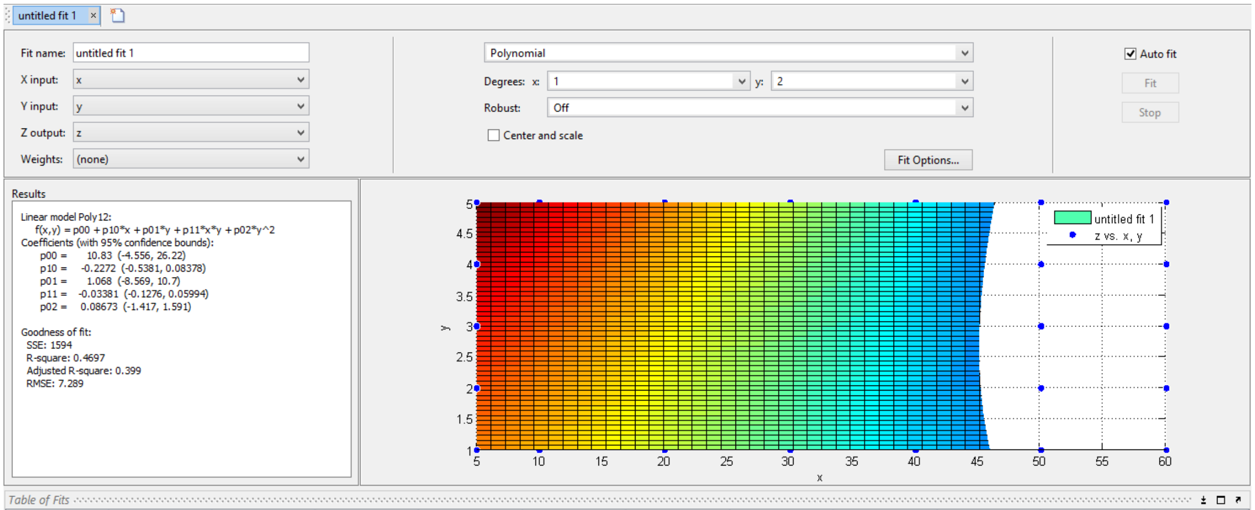


Figure 17: Contour 3 for toyota light

Nissan light

This is the 2-dimensional contour of the light intensity varying both x and y coordinates which are position of observer and position of light respectively. While the color show the intensity of light.

This is the contour graph by the linear interpolation method.

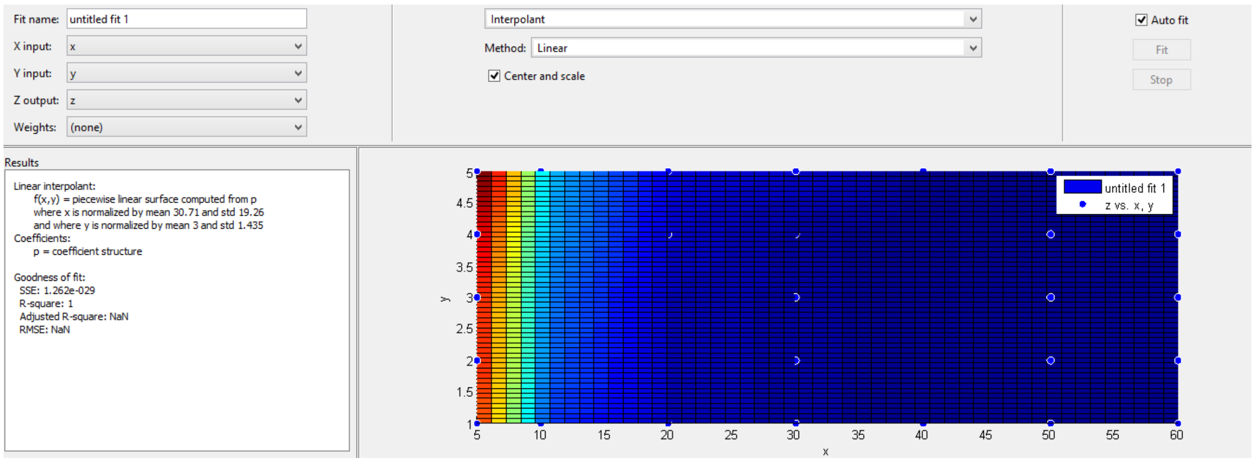


Figure 18: Contour 1 for Nissan Light

This is the contour graph by the nearest interpolation method.

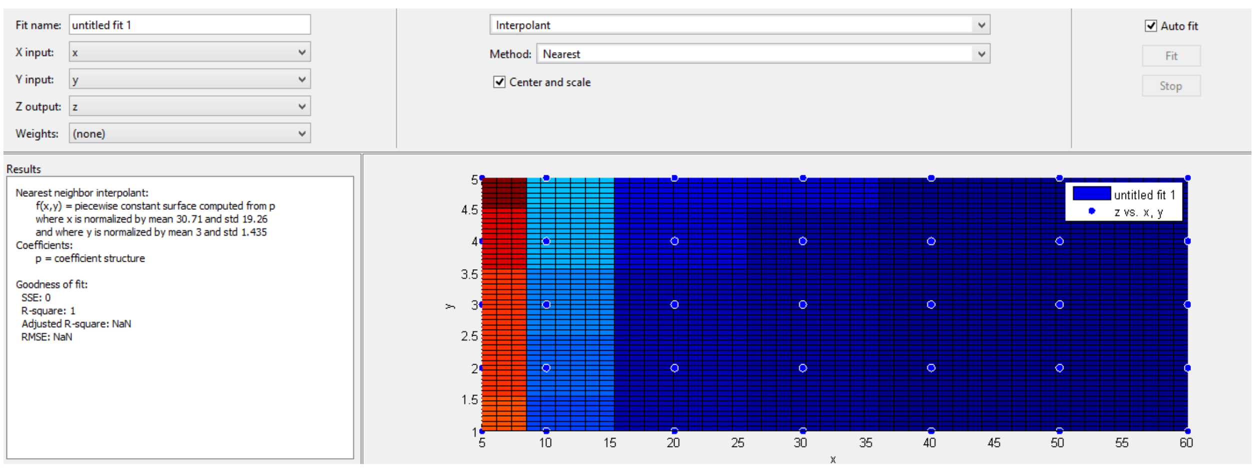


Figure 19: Contour 2 for Nissan Light

This is the contour graph by the polynomial interpolation method of degree one.

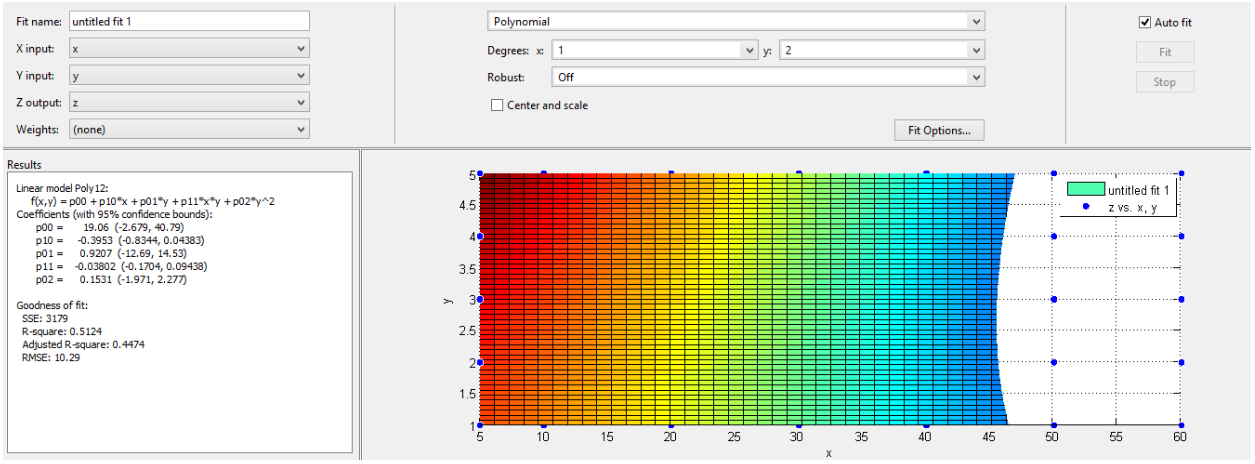


Figure 20: Contour 3 for Nissan Light

Hella LED

This is the 2-dimensional contour of the light intensity varying both x and y coordinates which are position of observer and position of light respectively. While the color show the intensity of light.

This is the contour graph by the linear interpolation method.

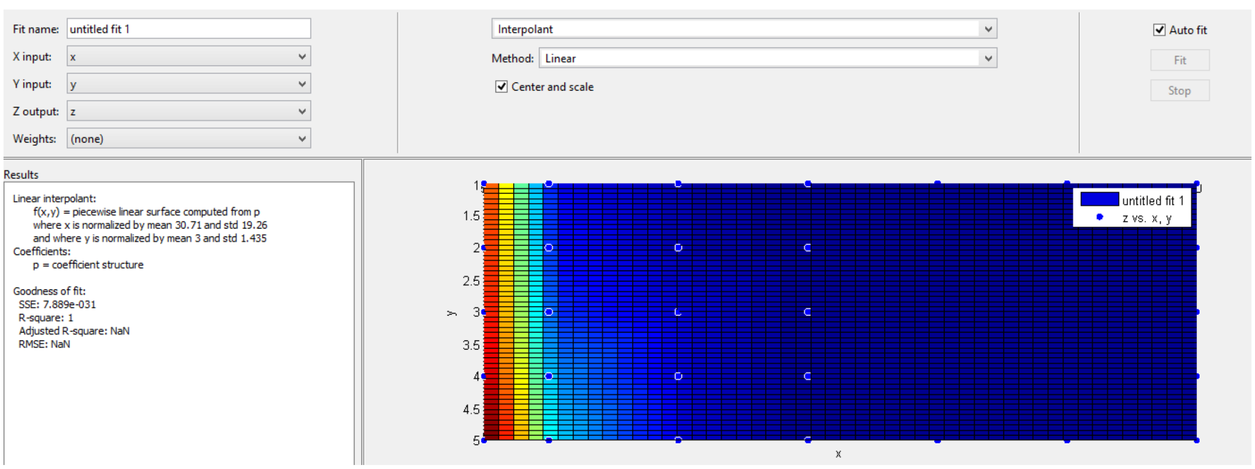


Figure 21: Contour 1 for HELLA LED

This is the contour graph by the nearest interpolation method.

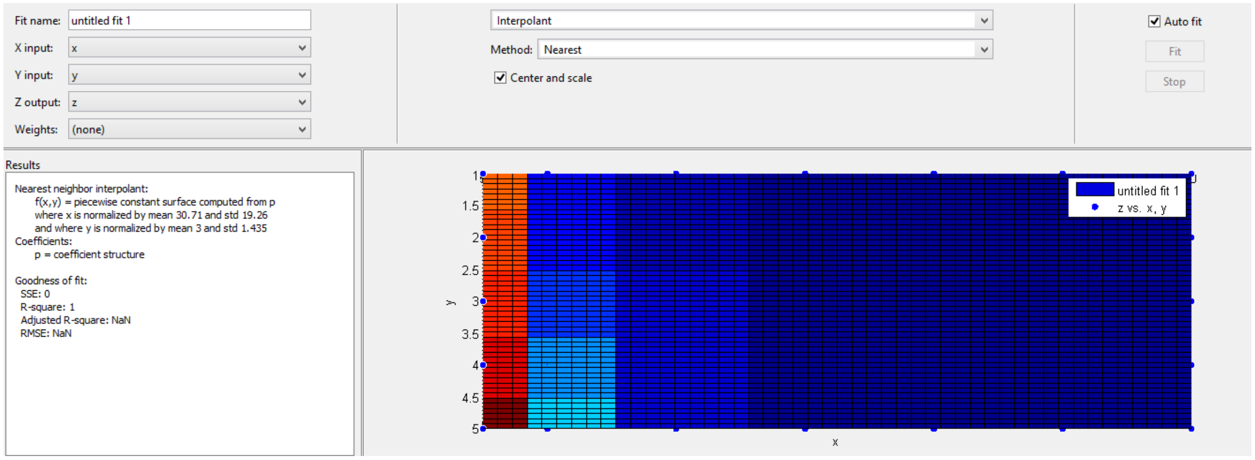


Figure 22: Contour 2 for HELLA LED

This is the contour graph by the polynomial interpolation method of degree one.

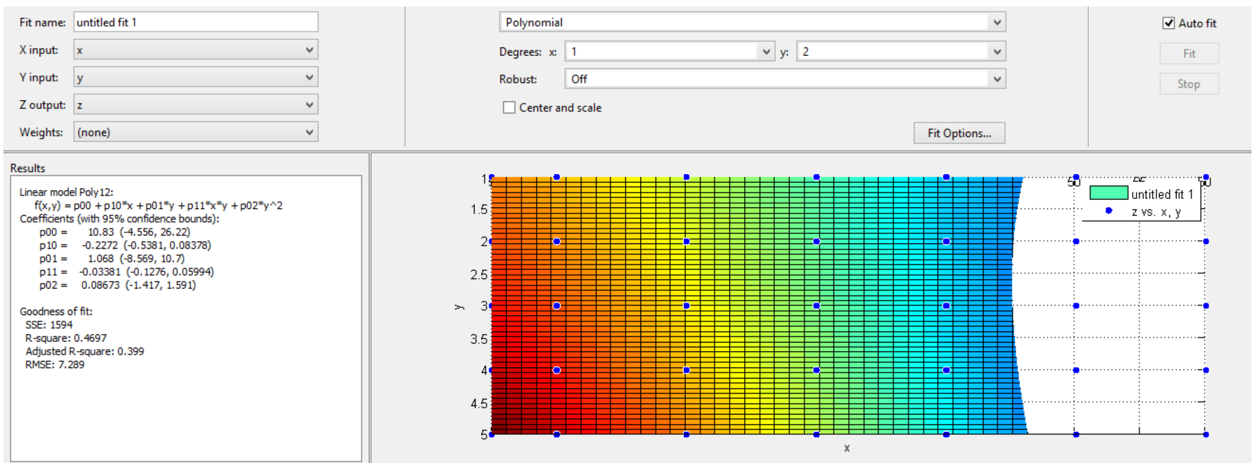


Figure 23: Contour 3 for HELLA LED

Hella Incandescent

This is the 2-dimensional contour of the light intensity varying both x and y coordinates which are position of observer and position of light respectively. While the color show the intensity of light.

This is the contour graph by the linear interpolation method.

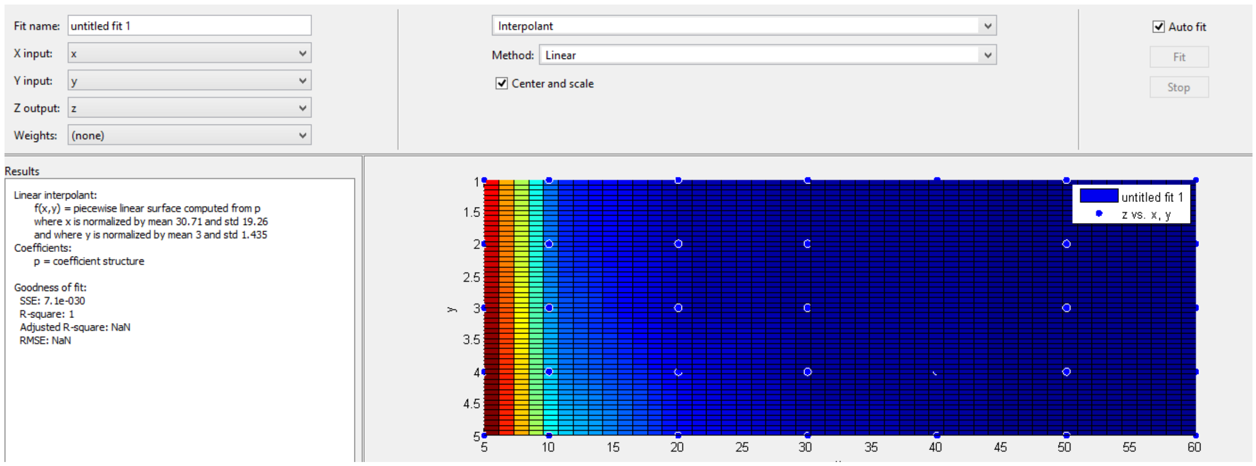


Figure 24: Contour 1 for HELLA Incandescent

This is the contour graph by the nearest interpolation method.

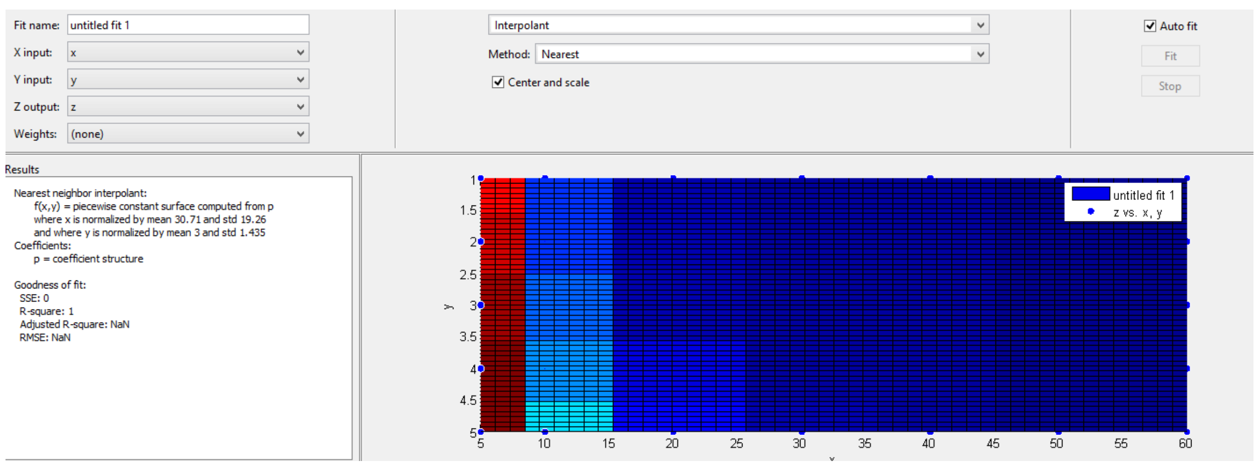


Figure 25: Contour 2 for HELLA Incandescent

This is the contour graph by the polynomial interpolation method of degree one.

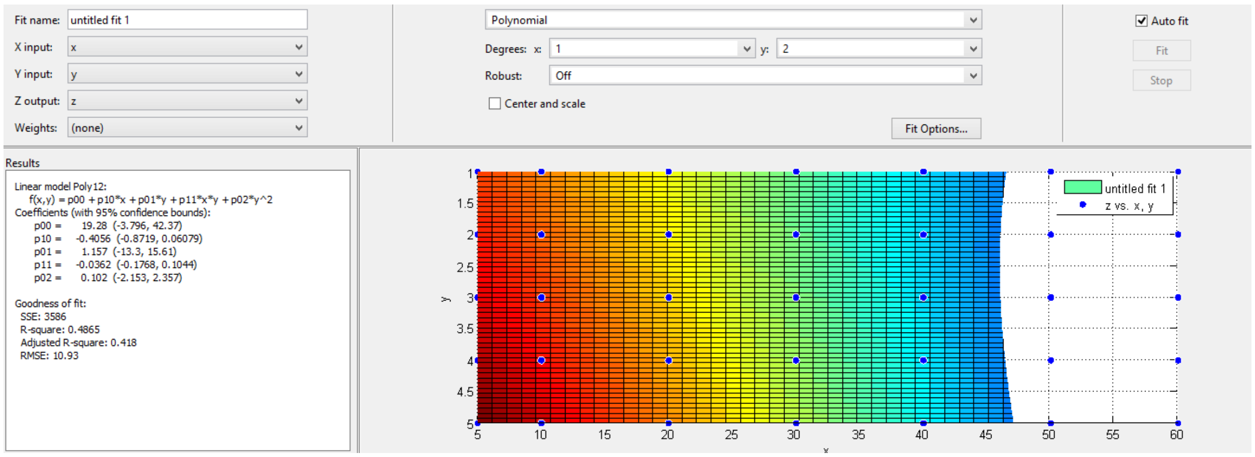


Figure 26: Contour 3 for HELLA Incandescent

Spot Light

This is the 2-dimensional contour of the light intensity varying both x and y coordinates which are position of observer and position of light respectively. While the color show the intensity of light.

This is the contour graph by the linear interpolation method.

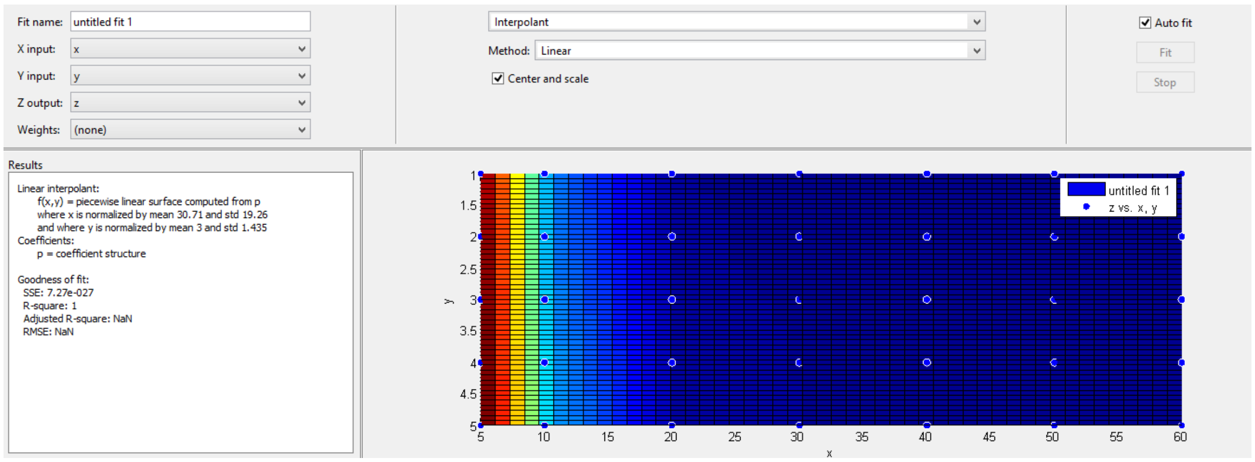


Figure 27: Contour 1 for Spotlight

This is the contour graph by the nearest interpolation method.

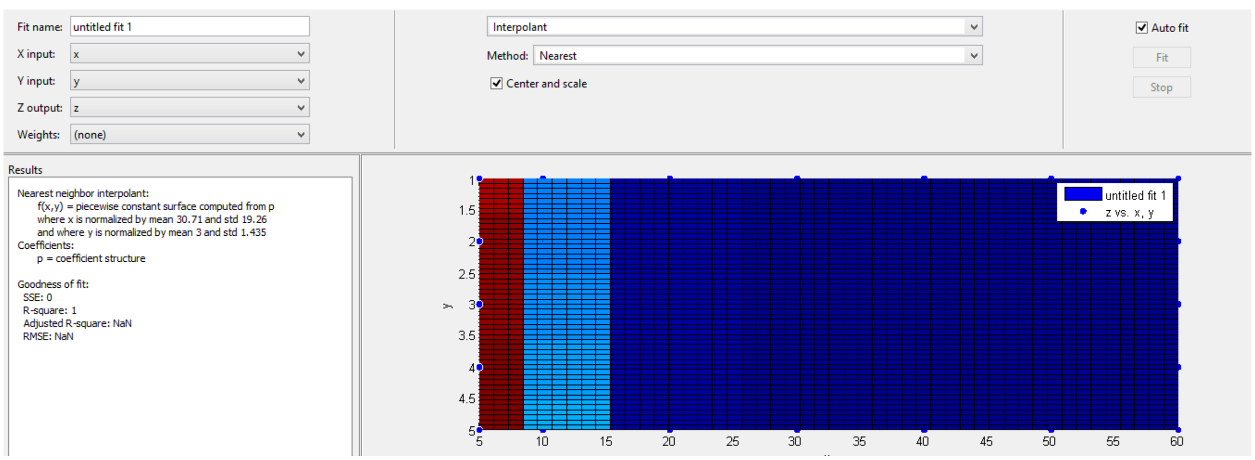


Figure 28: Contour 2 for Spotlight

This is the contour graph by the polynomial interpolation method of degree one.

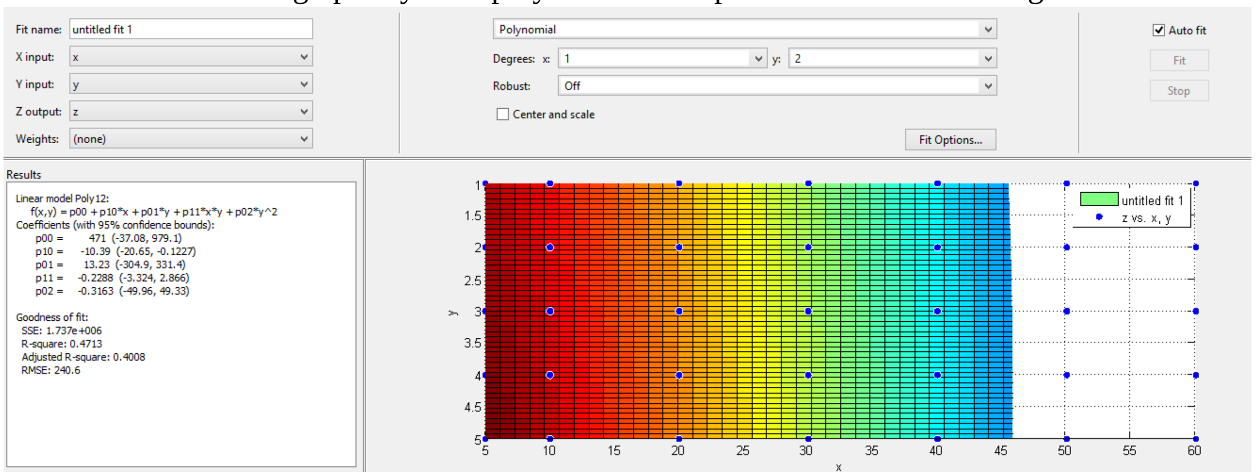


Figure 29: Contour 3 for Spotlight

Testing of fog lamps in laboratory settings

To get a better understanding of results obtained from the road testing of fog lamps we had to recreate those effects in a controlled lab setting and do a thorough experimentation on those experimental settings. The reason behind this approach was to do a one to one comparison under real fog conditions and in controlled laboratory settings.

The key factor in creating the exact road like fog conditions in laboratory was first of all creating a similar fog with a comparable fog density to what we saw at the motorway. The particle size of the fog created in laboratory had to be relatable to that to on road fog. The second major task was to create such a laboratory which had zero external light interference and where we could contain our fog with equal fog density all across the laboratory.

These two key factors were the driving forces in establishing our design of experiment for the second phase of this project. An enclosed room with zero light interference and real fog like conditions were the main two deliverables of this phase.

Construction of a Tunnel

To achieve both of our deliverable which had to create such an isolated room or enclosure where there was zero external light interference. Therefore we in coordination with the group 2 which was simultaneously working on this project decided upon building a tunnel where we can do our experimentation and validation of results. This tunnel will serve two features:

1. Containing fog in an isolated area
2. Preventing external light to interfere with the experimentation

The material covering the tunnel must have the following features:

- Nonreflecting surface
- Preferably water resistant
- Cost friendly
- Difficult to wear and tear
- Opaque material
- Light weight
- Easy to handle

Dimensions of Tunnel

The dimensions of tunnel were our next step in this process. What dimensions to be employed in the experimentation and validation of our results? Because creating a 60m long tunnel was an impossible feat to achieve. So we took a look back at our previous results which we obtained on the motorway. From there we saw a pattern of attenuation that each light followed. From there we saw that each light gave a maximum reading up to a range of 10m in z-axis. However if we moved further from the light, the light seemed to dim away exponentially.

Through research and discussions with our supervisors and on online forums we came to know of a law regarding this peculiar behavior of light.

Therefore the dimensions of tunnel best suited for our experimentation came out to be:

Table 19: Dimensions of tunnel

Feature	**Dimension**
Height	2m
Width	6m
Length	10m

These dimensions were best suited to study the pattern of light and also contain the fog from external factors.

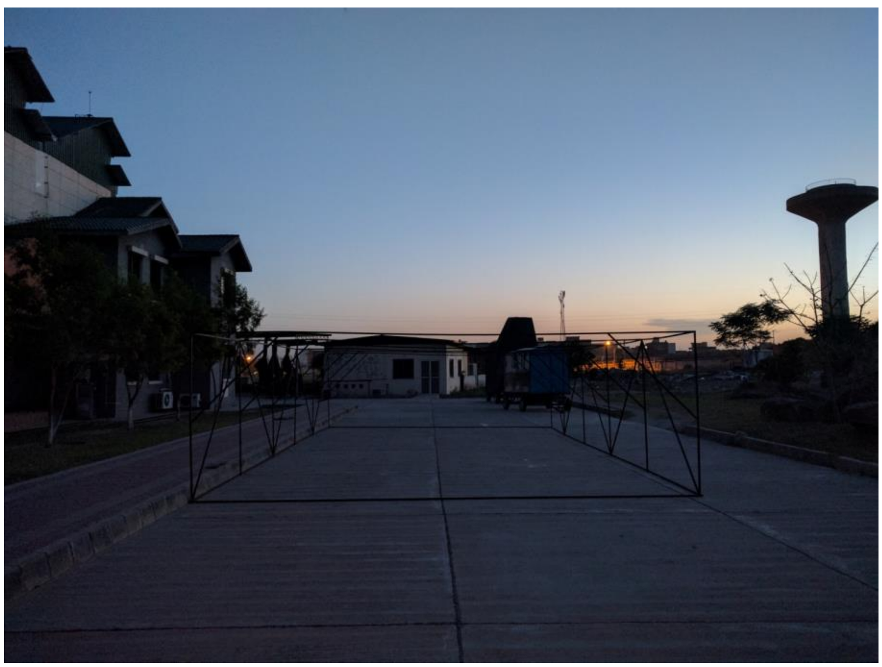


Figure 30: Tunnel structure

Creating Fog inside the Tunnel

To get if not similar a relatable fog inside the tunnel to that of what we observed on the motorway it was necessary to study the particle size and density per unit area of fog. Unfortunately as we cannot contain a sample of fog from road and study it in the laboratory, it was near impossible task to get the same results so we had to go with hit and trial approach to generate fog in our tunnel.

After a thorough research and fogging machine types and their mechanisms we decided to select a fogging machine with a power rating of nearly 1500 Watt. A fogging machine with a power rating similar to this will be able to give a relatable fog inside the tunnel. So the search of such fogging machine landed us in Lahore. The procurement of a similar fogging machine was done in the early April from a local market of Shalmi, Lahore.

Fog machine specifications

- Easy to use
- 1500 W power rating
- 80% water, 20% glycerin mixture
- 560 m3 fog output per minute
- 2.3 liter tank volume
- Can run for 3 to 4 hours with 250 ml of mixture.

The mixture proportion to be used inside the fog machine was totally dependent of what fog particle size we desired and the density of fog in particular area. As there is more scattering in small particle size of fog as compared to huge droplet sizes and our objective was to study the pattern of scattering therefore we opted a small particle size for our fog. The reason of more scattering in small droplet size of fog is because of the fact that if the droplet size of fog particles is small, there can be more number of particles adjusted in a certain area therefore causing more scattering in that particular area as compared to huge droplet sizes.

The exact proportion measurement were determined using hit and trial method where we kept on adding water to glycerin till be obtained the most favorable droplet size and density of fog. The last and most favorable proportion came out to be 80% water and glycerin mixture.

Both the mixtures were stirred very carefully till there was no suspension in the mixture and the solution as a whole was a clear mixture. The mixture was then fed to the fog machine and which in turn produced fog from that mixture. A 250ml bottle of that mixture was enough to carry out experimentation for 3 to 4 hours minimum. The fog machine worked in intervals and released fog in small packets after an interval of 30 seconds. This served two purposes.

1. The 30 seconds lag gave ample time to fog machine to recreate another packet of fog from the glycerin water mixture.
2. This 30 seconds lag was good for our experiment because the fog on motorway was mostly advection fog which came in patches suspended a few inches from the ground. This lag basically recreated that effect of fog and kept on sending fog inside the tunnel in packets.

Figure 31: Fog Machine

In Tunnel Obstacles, Markings and Reflectors

To recreate the effect of road and motorway inside the tunnel, road markings, road reflectors and obstacles were placed inside the tunnel.

Obstacles

- Objects made of polyurethane sheet introduced into the tunnel.

- Grey, Lambertian reflectance
- Placed at varying distances
- Purpose to test contrast in fog

Reflectors

- Reflecting tape at various heights to decide how high reflectors on the road side should be placed

Road Markings

- Road lane markings on the ground to observe how obscured vision effects road visibility.
- 8.5 ft wide lane with a 5 inch wide marking at a distance of 5 ft.

Design of Experiment

The design of experiment for our prior experiment was testing of each light at different heights and at different lengths. However this time our main focus was to also check the dispersion of light in the x axis along with y and z axis. So for this we decided to take a reference vehicle and do the experimentation at the height of fog lamps of that vehicle. For this modifications also needed to be made in the light assembly.

- Take lux readings of each light at 4 points in z axis. These 4 points were at 2.5 m distance from each other.
- Take lux reading at the back of the light to study the backward reflection of light due to fog.
- Take lux reading at the line of sight of driver to study the reflection in the eyes of driver thus causing him to blind momentarily.
- Repeat this experiment at 2 different heights. One at the height of fog lamps and the other at the height of head lights.
- Calculate the spread and beam angle of each light.

Figure 32: In-door experimentation

Reference Vehicle

Reference vehicle for our project was Honda City. Reason for taking a reference vehicle is standardize our experience with respect of a vehicle and to specify the heights of headlights and fog lights as well as the distance between the lights. Total length of Honda City front is 1.694 meters and distance between two headlights was 1.52 meters. Same was the distance between two fog lights. Height of fog lights is 38 centimeters from the ground and height of headlights is 71 centimeters. This height was measured accurately in order to make the experiment accurate. Honda city was chosen because it is very commonly used vehicle in Pakistan and has a average sized front and an average height (not much high not much wide body).

Modification in assembly

Our 1st experiment was not dependent upon original and accurate distance between lights (fog lights as well as headlights) because that experiment was conducted to analyze the behavior of light in fog so considerable modification was required.

- Modification was needed in order to maintain a constant distance between the fog lights and headlights (1.52 meters) as well as the height (38 centimeters in case of fog lights and 71 centimeters in case of headlights). First of all the angle iron on which the lights were mounted was replaced with a wider angle iron. This new angle iron had holes 152 centimeters wide to maintain the lights at constant distance. One fog light and one headlight was mounted at a time.
- Electrical connection were modified in order to provide current to the lights. Wires were rearranged. Switches were reassigned. The two batteries were connected to the circuit. One battery gets disconnected when 12V lights were used and was reconnected when the Hella 24V light was used.
- Both batteries were 12 Volts and 150 ampere-hour this time, instead of one smaller battery of 12v and 40 ampere-hour because smaller battery discharges earlier. Although 40 ampere-hour battery is usually used in vehicles but it was not feasible with our experiment because in case of car, battery charges continuously as the vehicle's engine is running. But in our experiment continuous was not possible. So bigger batteries were used.
- Connectors were replaced by crocodile clips on 2nd battery because it was easy to remove.
- Another modification was removal of two pipes that provide extension in length, removing telescopic arrangement. Because this time experiment was to be performed at lower heights (38 centimeters in case of fog lights and 71 centimeters in case of headlights). So the modified assembly was of almost 1.7 meters instead of 5 meters.

- Power supply was also used in this experiment. Power supply can provide 12 volts as well as 24 volts when needed. This experiment was conducted in tunnel where electrical supply is available so using a power supply was also feasible. Power supply accurately and effectively provided the required current and voltage to each light.
- The 2nd assembly, that was the receiver assembly, where lux meter was mounted, was not included in this experiment because in this experiment the spread of light was to be measured at lower heights. So lux meter was operated by holding in hand and values were observed.

Spread and Beam Angle

According to the international standards of SAE a light must have a horizontal spread of at least 20ft because normally when a driver is driving on a two lane road he must be able to see both the edges of road. The normal width of one lane by international standards is 8.5 ft and taking in account the reflecting markings it is rounded off to 10 ft in general. Therefore for a two lane road the driver must have a 20 ft spread of fog lamps in order to view both the edges of road.

According to SAE standards the lights testing of automobiles is done at a distance of 25 ft. This distance is calculated taking in account the reaction and mean braking time of the driver if he is travelling at a nominal speed of 60 km/hr.

So at 25 ft a driver must be able to view clearly what is at the other end and also both the edges of road and for this a generally the beam angle of lights is kept to be 44 degrees.

Table 20: General specfications

Nominal Spread	20 ft
Distance	25 ft
Beam Angle	44^o

Calculating Spread of each light

In order to calculate the spread of each light we calculated the area which each light covered horizontally in the x axis. This distance was calculated manually with the help of a measuring tape.

Table 21: Spread of each light

Light	**Spread**
HELLA LED	32 ft
HELLA Incandescent 24V	26 ft
Toyota	22 ft
Nissan	17 ft

Mathematical Calculations

Minimum Spread = 20 ft

Distance = 25 ft

$$\tan \emptyset = \frac{25}{20/2} \quad \text{(Eq. 1)}$$

$$\emptyset = \arctan 2.5 = 68.19° \quad \text{(Eq. 2)}$$

$$\theta = (90 - \emptyset) x\ 2 \quad \text{(Eq. 3)}$$

$$Beam\ Angle\ \theta = 43.62°\ or\ 44°$$

Figure 33: Hella LED cut-off

Figure 34: HELLA Incandeceant cut-off

Table 22: Beamm Angles

Light	**Beam Angle**
HELLA LED	65^0
HELLA Incandescent 24 v	55^0
Toyota	47.5^0
Nissan	37.5^0

CHAPTER 4

RESULTS

Testing of lights was performed at various distances and heights depending upon various reasons like studying attenuation, backward scattering etc. Results of various lights are as follows.

Hella LED

First of all the forward scattering of light is to be measured. Light was measured at a distance of 2.5 meters, 5 meters, 7.5 meters and 10 meters. Values are

Table 23: Hella LED

Distance	Luminosity of light (lux)
2.5 m	32
5 m	12
7.5 m	7.5
10 m	5.2

In order to measure the effect of backward reflection, lux meter was placed on top of light to get the idea about amount of light reflected back due to scattering from the fog and dust particles. The value of backward reflection was 17.7 lux for this light.

In order to measure the light received by driver, lux meter was placed 4 ft above ground just above the left light because the driver is on the left front seat of car. The value of luminosity of this light was 7.5 lux.

Hella Incandescent

First of all the forward scattering of light is to be measured. Light was measured at a distance of 2.5 meters, 5 meters, 7.5 meters and 10 meters. Values are

Table 24: Hella Incandecent

Distance	Luminosity of light (lux)
2.5 m	246
5 m	78
7.5 m	29
10 m	13

In order to measure the effect of backward reflection, lux meter was placed on top of light to get the idea about amount of light reflected back due to scattering from the fog and dust particles. The value of backward reflection was 37.1 lux for this light.

In order to measure the light received by driver, lux meter was placed 4 ft above ground just above the left light because the driver is on the left front seat of car. The value of luminosity of this light was 13.4 lux.

Toyota 12V light

First of all the forward scattering of light is to be measured. Light was measured at a distance of 2.5 meters, 5 meters, 7.5 meters and 10 meters. Values are

Table 25: Toyota

Distance	Luminosity of light (lux)
2.5 m	131
5 m	123
7.5 m	97.6
10 m	74.2

In order to measure the effect of backward reflection, lux meter was placed on top of light to get the idea about amount of light reflected back due to scattering from the fog and dust particles. The value of backward reflection was 97.2 lux for this light.

In order to measure the light received by driver, lux meter was placed 4 ft above ground just above the left light because the driver is on the left front seat of car. The value of luminosity of this light was 90.2 lux.

Nissan 12V light

First of all the forward scattering of light is to be measured. Light was measured at a distance of 2.5 meters, 5 meters, 7.5 meters and 10 meters. Values are

Table 26: Nissan

Distance	Luminosity of light (lux)
2.5 m	130.6
5 m	45.8
7.5 m	30
10 m	12.3

In order to measure the effect of backward reflection, lux meter was placed on top of light to get the idea about amount of light reflected back due to scattering from the fog and dust particles. The value of backward reflection was 49.5 lux for this light.

In order to measure the light received by driver, lux meter was placed 4 ft above ground just above the left light because the driver is on the left front seat of car. The value of luminosity of this light was 41.2 lux.

Discussion

Particle size

Density of fog and fog characterization basically and effectively depends upon the size of particles of fog. Fog is not the same everywhere somewhere fog is dense and somewhere shallow or moderate. Size of particles plays an important role here. Density and particle size of fog is not same everywhere and depends upon the area, its geographical specifications, climate conditions, temperature, humidity etc.

Particle size of fog also plays an important role in the visibility in fog using a particular light. So basically if the particle size of fog is large than it means that the density of fog is low because less number of particles will be packed in a particular volume with more empty space between particles. So density of fog will be less and fog will be shallow or moderate. So in case of shallow fog with the largest fog particles, due to larger particle size, scattering will be minimum and more and more light will be able to pass through the fog. So visibility will be maximum in such fog conditions.

Particle size, in case of moderate fog will be medium. So the scattering will be normal and visibility will be less than shallow fog but more than dense fog.

In case of dense fog, the particle size is smallest. Smaller particle will be packed more effectively in a specific volume. More number of particles will be able to pack inside a fixed volume if particles are small. So density will be high and scattering will be high. So light will be scattered more and less light will be able to attenuate.

Beer-Lambert Principle

Beer Lambert law is basically a law that explains the relation between the visibility of light (as perceived by eye) and the luminosity of light. Beer Lambert law states that if the value of luminosity of light increases 10 times than the visibility of light increases twice only. This also means that if the light's luminosity decreases 10 times than it would not affect the visibility that much and the visibility decreases by half only.

So if a particular light is used in the experiment in which the attenuation of light is to be analyzed, greater increase or decrease in the luminosity does not produce the same effect on the visibility of light. Even if the luminosity of light is doubled the visibility would not change that much, even it may not be noticeable. Same goes with the decrease in the luminosity by half, it wouldn't be easily recognizable either. It would require the increase or decrease in luminosity by 10 times to increase or decrease visibility by two times respectively.

So when working with a particular light, it is observed that what the pattern of attenuation of light is. A light that has a high luminosity value at the start but at the end of the path of attenuation, luminosity value is very low, would never be preferred because it shows large scattering and backward reflection. On the other hand, the light that shows less decrease in the value of luminosity along its path of attenuation will show that scattering is less.

So in our case, best light will be that one which fits perfectly with the Beer Lambert's law and less backward scattering. A light will be the best fit if its value of luminosity is decreasing less because in that case the backward scattering will be less. But visibility will have not affected. A light that decreases considerably along its path of attenuation will depict that backward scattering is much high and visibility is also reduced considerably.

According to SAE standards, for a driver, to respond to something seen on road and apply brake, the response time is almost 1 second. This means that a driver needs almost 1 second to press the brake pedal in order to apply brake after seeing something on road. So visibility of light on road should be such that driver should be able to see clearly within 25 feet so that he may stop the vehicle in time. So for that reason the distance is set to be 25 feet.

Deduction of results

Table 27: Deduction

Light	Backward reflection (line of sight of driver)
Hella 12v LED	7.5
Hella 24v	13.4
Toyota Fog lamp	90.2
Nissan Fog lamp	41.2

As evident from the results above and viewing these results in the light of Beer-lambert law. The forward attenuation of all the lights lie in the ideal visibility range but where does the difference lie such that the HELLA LED light is not effective in fog according to visual inspection. The answer to this lies in the following key points:

- The contrast of light with that of the background.
- Backward reflection of light to the eyes of driver

According to beer Lambert law when the lumen per meter square re decreased approximately10 time's depreciation in visual inspection is nearly halved. Therefore if the light is giving 300 lumens at 25 feet and other light is giving 200 lumens at 25 feet then there will be no clear visible change in the visibility of light at the other end but if we take in account he backward reflection of light. If one light is giving 100 lumens per meter square and other one is giving in range of 10-20 l1umens per meter square there will be a district visual change as the backward reflection is doubled in the prior light thus causing blindness to the eyes of driver.

- The backward reflection (into the eyes of driver) in case of Nissan and Toyota fog lamps is much higher that of Hella Lights.
- So because of the high backward reflection of Toyota and Nissan lights, they are not to much efficient in fog conditions.

Comparison of Hella LED and Hella Incandescent

Comparison between Hella LED and Hella 24v, forward attenuation, is shown in the form of table

Table 28: Comparison

Distance	Luminosity of light (Hella LED)	Luminosity of light (Hella 24V)
2.5 m	32	246
5 m	12	78
7.5 m	7.5	29
10 m	5.2	13

From the table it is clear that luminosity of Hella 24v light is higher than the Hella LED light. But decrease in light during forward attenuation is also high. At the end (10m) the luminosity of both lights is almost the same (keeping in mind Beer Lambert's Law). So both lights are the same.

Now the backward reflection (in the eye of driver) in case of Hella LED is almost 9 lux and in case of Hella 24v is 13 lux. Keeping in mind Beer Lambert's law, this difference is not visible. So effect of reflection is same in both cases. So theoretically, both the lights are almost the same and equally efficient.

Effect of contrast

Contrast is one of the most important and key factor that determines the visually of the road and objects on road. If the light is in color contrast with the object on which it falls, it is clearly visible and if the contrast is low than even having a high luminosity would not make the object that visible. So contrast is an important factor.

In case of lab experiment, the subject on who light was subjected was dark so Hella LED was much effective because it was white and produces much contrast. However in case of road, yellow light, the Hella 24v light is much more effective because it would produce much more contrast with vehicles of various colors specially white and light colored vehicles.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

This project provided with immense learning opportunity and opportunity to link with the industry and gain valuable input from professionals such as technical lead at HELLA and officer in charge from National Highway Authority. A glimpse of conclusion in the form of bullet points is mentioned below as:

- Reflective markings and aiding equipment for passive safety should be mounted at heights where there is less fog.
- The reflecting cones and markings are often invisible on curves of road. If they are pleased at height they can be of great help as fog is a boundary layer phenomena and sets near the surface of ground.
- The reflecting marking and indicators must be placed at height of 4 to 6 m from the ground for the drivers to see them properly.
- On road vehicles should necessarily be equipped with rear fog lamps.
- The greater the beam angle of fog lamps, the better. Minimum beam angle of 44^o.
- The spread of fog lamps must be at least 20 ft.
- The inner optics of fog lamps must be designed in such a way that it maximizes the inner beam angle.
- The backward reflection light to the eyes of driver because of fog lamps must be kept as least as possible.
- The effective distance for fog lamps to work properly is 25 ft at a speed of 60 km/hr. Therefore manufacturing fog lamps that give powerful light intensities at distances greater than 25 ft is redundant.
- The main focus in creating fog lamps must be shifted from maximizing intensity at the receiving end to maximizing the spread and reducing the backward reflection. This is dependent upon inner optics of each lamp.

- There must be a distinct and clearly defined cut off of the fog lamps to maximize foreground and road edge visibility.
- The fog lamps must be pointing towards the road as fog is still suspended a few inches from the ground, there will be less scattering and backward reflection.
- Contrast plays one of the main roles in characterizing visibility of light. Light should be of such color that has a distinct contrast as compared to the background.
- Yellow paper technique is pre dominant on road. Yellow color is most receptive to human eye's cone cells and human eye catches this color the quickest. Therefore yellow lights can be more suitable while driving.
- On road there can be white cars too in a dark background, therefore yellow color lights provide the best contrast against such situation also.
- A website is being under construction, made to facilitate motorway officials and drivers. Through this website motorway administration will change the color of the certain area according to the fog density and visibility and accordingly provide suggestions for traveling or any inconvenience.
- The link of the website is: http://m2-fog.tk/

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APPENDIX

Calculating Beam Angles from Spread

Beam angle of HELLA Incandescent

Spread = 26 ft

Distance = 25 ft

$$\tan \emptyset = \frac{25}{26/2} \qquad \text{(Eq. 1)}$$

$$\emptyset = \arctan 1.92 = 62.5° \qquad \text{(Eq. 2)}$$

$$\theta = (90 - \emptyset) \times 2 \qquad \text{(Eq. 3)}$$

$$Beam\ Angle\ \theta = 55°$$

Beam angle of HELLA LED

Spread = 32 ft

Distance = 25 ft

$$\tan \emptyset = \frac{25}{32/2} \qquad \text{(Eq. 1)}$$

$$\emptyset = \arctan 1.56 = 57.33° \qquad \text{(Eq. 2)}$$

$$\theta = (90 - \emptyset) \times 2 \qquad \text{(Eq. 3)}$$

$$Beam\ Angle\ \theta = 65°$$

Beam angle of Toyota lights

Spread = 22 ft

Distance = 25 ft

$$\tan \emptyset = \frac{25}{22/2} \quad \text{(Eq. 1)}$$

$$\emptyset = \arctan 1.92 = 66.25° \quad \text{(Eq. 2)}$$

$$\theta = (90 - \emptyset) \times 2 \quad \text{(Eq. 3)}$$

$$Beam\ Angle\ \theta = 47.5°$$

Beam angle of Nissan lights

Spread = 17 ft

Distance = 25 ft

$$\tan \emptyset = \frac{25}{17/2} \quad \text{(Eq. 1)}$$

$$\emptyset = \arctan 2.94 = 62.5° \quad \text{(Eq. 2)}$$

$$\theta = (90 - \emptyset) \times 2 \quad \text{(Eq. 3)}$$

$$Beam\ Angle\ \theta = 37.5°$$