ABSTRACT

TRANSMISSION OF LIGHT AND AUDIBLE SOUND IN A SYNTHETIC FOG MEDIUM

by
Bhavin Babaria

The primary goal of the thesis was to study the propagation of visible light and auditory sound through a synthetic fog medium compared to an ambient air environment. It is known that the fog substantially decreases the visibility however; this has not been studied quantitatively. Further information regarding other energies such as sound is also needed to understand how the energy reacts in the fog medium. The extent of visual and auditory degradation in humans needs to be investigated. Researchers have studied light transmitted through water, air; however, no one has studied how light or sound is transmitted through a synthetic fog medium. The first aspect of this thesis was to build the appropriate environment for the experiment, which used light sensors to detect the intensity of the light, and a sensitive microphone to detect the frequency of sound in an unknown environment. Lab-VIEW, a graphical programming language, was used to gather data for the sound experiment. Data were then analyzed by graphing the relationship of intensity of sound vs. distance vs. different production level of fog and frequency vs. distance vs. different production level of fog in the varying density of the synthetic fog medium. The data, which were collected from the light meter, in the fog medium, were then compared with the data collected in the room filled with ambient air. Similarly, the sound energy was detected using a microphone, in the synthetic fog medium, which was compared with the sound signal transmitted in an ambient air environment.

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by
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This thesis is dedicated to my parents. Thanks to my sister, Nilam, and my wife, Bhavika, for their enormous support throughout this thesis.

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CHAPTER 1

INTRODUCTION

1.1 Objective

The goal of this project was to analyze the transmission of audible and visual energy in an air environment, and compare it to results obtained from an environment filled with a synthetic fog medium. This research determined the amount of light and audible sound waves emitted through different density levels of the fog compared to the control, which is ambient air. This study also answered the following question: does the data collected through the light sensors and microphones in a fog medium correlate to data collected using the same protocol but from the environment without fog?

Researchers have studied sound in water and in air. Sound travels faster in the water compared to air [2]. " The speed of sound in water is 4.4 times faster in water than in air where the exact speed of sound in water is 1438 m/s, when the temperature of the water is 8 degrees Celsius."[2]. To date, no study has been conducted to quantify how sound travels in a fog medium. The key question this research addressed is, does sound and light travel faster or slower in a fog medium compared to an air medium. "The NTSB noted that in 1990 and 1991, four multiple-vehicle accidents were caused by fog on limited-access highways in the United States, involving more than 240 vehicles, had resulted in 21 fatalities and more than 90 injuries. In addition, the NTSB noted that between 1981 and 1989, accidents where fog was present on all classes of highways in the United States had resulted in more than 6,000 deaths. Although this is a small percentage of the total accidents, they are catastrophic and generally attract national media attention"[3] (NTSB-National Cooperative Highway Research Program). Many deaths would have been prevented if appropriate traffic control techniques were available for the drivers in adverse conditions such as an environment filled with a fog medium. To create such safety devices, a visibility study is required. A key aspect of this research quantified the amount of light transmitted through a synthetic fog medium.

A synthetic fog machine was used as a source to generate the fog medium to be studied in this project. Fog is comprised of distilled water (22% by weight), glycerin (9%) and triethylene glycol (69%). Several studies have been conducted on the health risks imposed from synthetic fog on humans. The use of synthetic fog in theatrical activities has increased over the years. The National Institute of Occupational Safety and Health (NIOSH) conducted a study in 1990 through1991 where they concluded that actors who were exposed to theatrical effects (smoke with glycerol and glycol) showed increased rates of asthma compared to actors who worked in musical productions that were not exposed to glycerol and glycol. Moline and colleagues studied 439 Broadway actors, who were exposed to the smoke (fog) such as the pyrotechnic theatrical effects which also uses glycerol, and concluded that there were health risks associated with exposure of actors to high levels of glycol smoke and mineral oil [4]. If the high level of glycol is avoided then actors should not be harmed. Finally, the glycol concentration should not exceed 40 mg/m^3 to avoid hazardous effects to the human body. "Pyrotechnics as currently used on Broadway, do not have a substantial effect on Actors' health." [4]. Synthetic Fog particles are equal to or less than 1 micron. The liquid used to create the synthetic fog is non-hazardous according to The Occupational Safety and Health Administration (OSHA) Hazard communication standard 1910.1200, subpart "Z" for "Toxic and Hazardous" substances [5].

1.2 Background Information of Light and the Human Eye

Light is one of the energies that will be transmitted into the two environments studied, the laboratory filled with ambient air (the control) and the laboratory filled with a synthetic fog. In order to understand the resultant data thoroughly, basic characteristics of light need to be studied. Section 1.2.1 provides background information on the basic properties of the light. Furthermore, it is important to understand how humans detect light. The human eye is a sensor that detects light and provides electric signals to the brain where the brain makes decisions based on the sensory input information. The physiology of the eye will be described in section 1.2.2.

1.2.1 Light

Isaac Newton analyzed and experimented with the colors of light through a prism in 1672 [6]. Newton emitted white light through the prism and seven different colors were produced as a result. The seven colors (red, orange, yellow, green, blue, indigo, violet) were further studied to determine the wavelength. Red has the longest and violet has the shortest wavelength.

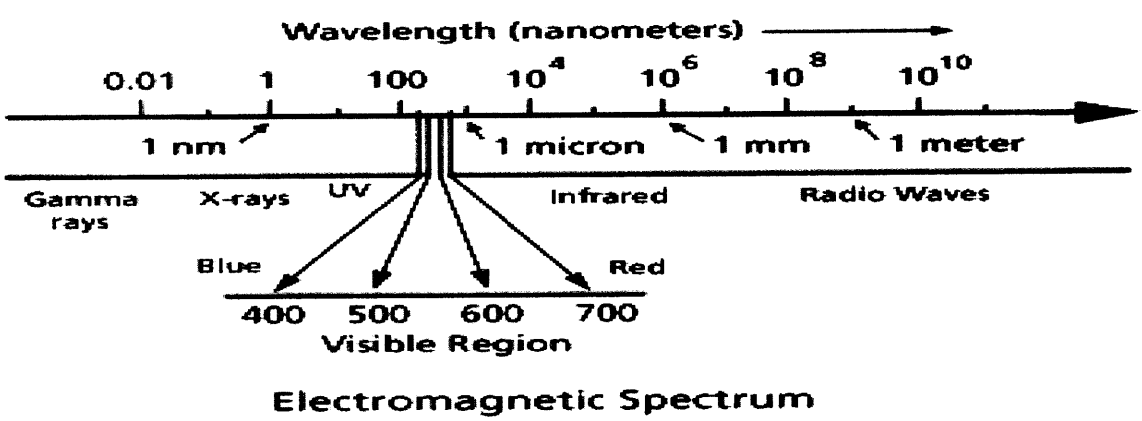


Figure 1.1 Electromagnetic spectrum [6].

Light is quantified by its wavelengths (figure 1.1), which is the distance between the two peaks of a light wave where the symbol for wavelength is lambda (λ). For example; red, yellow-green and violet have wavelengths of 680nm, 550nm, and 410nm, respectively. Humans can see colors between 400 and 700 nanometers (nm) of wavelength [6]. The intensity of the light is defined by flux or luminance. Two spectrums, which the human eye does not detect, are infrared light (above 1000nm) and ultraviolet light (below 400 nm).

1.2.2 Physiology of Eye

The eye is a sensitive and complex sensory organ. Vision is possible when light enters the eye through the pupil. The pupil is a round shape located in the iris. In a dark environment, the pupil expands in order to allow as much light as possible to enter. In the presence of a brighter environment, the bright pupil decreases in size to allow adequate light through from the source. The iris is a muscle that controls the aperture of the pupil. Once light passes through the pupil it progresses to the lens and then is projected to the fundus of the eye or the retina. The retina converts the image into an electrical signal, which propagates through the ganglion cells that comprise the optic nerve. The signal progresses to lateral geniculate nucleus and proceed to the visual cortex in the brain. [7]

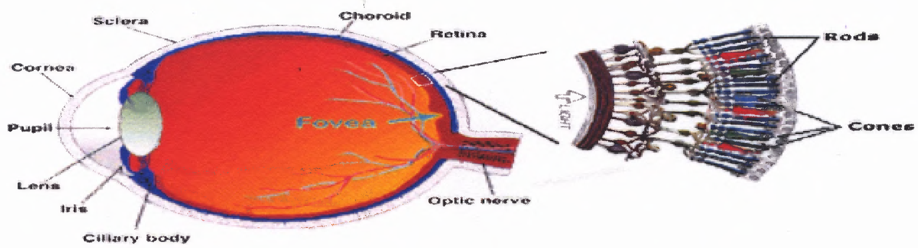


Figure 1.2 The physical anatomy of eye [8].

Each eye has three layers (tough outer layer, middle layer, and inner layer) through which light passes before going to the brain via the optic nerve (figure 1.2). The outer layer is composed of the sclera and cornea. The sclera is a white outer cover of the eye, which is mostly composed of the protein collagen. The cornea is the outer layer in front of the eye. It is transparent and colorless. The cornea is composed of five layers where the outermost layer is called the epithelium, which is for the transparent material of the cornea. It does not contain any blood vessels, but it gets its nutrients from surrounding fluid and the vessels. The middle layer of the cornea consists of the choroids, the ciliary body and the iris. The ciliary body is the organ, which allows the lens to change its concavity and is used to focus an object. As the ciliary body contracts, it allows the lens to attain sharper focus. The lens is soft for younger people, typically younger than 35 years old; however, as a person ages the lens looses its elasticity. The iris is also part of the middle layer of the cornea. The iris is a muscle and controls the amount of light entering into the eye. It protects other organs within the eye from the light overexposure. The last layer is the inner layer, which is the retina.

Within the retina is the fovea. The fovea is very delicate part of the retina, mostly used for sensitive vision and contains acute cones (approximately 7 million in each eye) and rods (approximately 125 million in each eye)[9]. There are five types of cells in the retina; photoreceptors (rods and cones), bipolar, amacrine, horizontal, and ganglion cells. The optic nerve is mostly composed of ganglion cells, which passes electrical signals to the lateral geniculate nucleus (LGN). From the LGN, the signal traverses to the occipital lobe within the back of the brain. The cells of the primary visual cortex (V1), located in the occipital lobe, are the first ones to receive the signals from the lateral geniculate.

Signals conveying color information then go on to several nearby visual areas for further processing located in V4 [9].

1.3 Background information on Sound

Sound energy was also quantified in two environments, one in a laboratory of ambient air and one in a laboratory filled with synthetic fog. Sound frequency was recorded and the sound intensity level measured in decibels (dB) was calculated. This research used a microphone to detect sound waves that are audible to the human auditory system. In this project, sound has been detected from a highly sophisticated microphone; Humans detect sound waves through the ear which contain hair cells, that transduce frequency into electrical signals. The ear may appear simple from outside, however there are many complicated stages through which sound waves must pass through before they traverse to the brain. In this project, the microphone measures the sound waves as a voltage value which was converted to a decibel (dB) level by using the dB formula specific for that microphone. The human ear has a similar process; Section 1.3.2 will discuss the human physiology of the ear and how it is similar to the microphone based intensity calculation discussed in Section 1.3.1.

1.3.1 Sound Waves

Sound travels through solid, liquid and gas mediums as mechanical waves, except sound waves cannot travel within a vacuum. The speed of sound varies as it goes through a different medium (solid, liquid, gas). For example, the speed of sound at a temperature of 20^0 C in air, water, glass, hard wood, and helium is 343 m/s, 1560 m/s, 4500 m/s, 4000 m/s, and 1005 m/s respectively [10]. Humans can only hear sound waves, which have frequencies between 20Hz and 20kHz, known as the audible range. Sound frequencies, below 20Hz (termed infrasonic sound) and above 20kHz (termed ultrasonic sound) cannot be heard by humans. However, many animals have the capability to hear ultrasonic waves; dogs can hear up to 50kHz, whereas bats hear sound frequencies up to 100kHz.[10]

Ultrasonic waves are widely used in medical applications and diagnostic equipment. Earthquakes, volcanoes, thunder and vibrating heavy machinery are all examples of events that produce infrasonic sound. The intensity of sound is consistent if measured by a microphone; however, people have different perceptions of sound intensity. The human ear can detect sounds over a vast range of intensities, it can hear as low as 10^{-12} W/m^2 ("threshold of hearing") and as high as 1 W/m^2 (threshold of pain). Because of this wide range of intensity, the ear perceives signal "loudness" approximately logarithmically with intensity, a unit called the decibel (dB), which is related to the logarithm of the intensity of sound typically denoted in W/m^2. Sound intensity is measured in watts per square meter (W/m^2) and can be translated to a corresponding decibel (dB) level. Sound intensity level is logarithmically related to the sound intensity as shown in equation (1). This is the standard formula used to calculate the sound intensity level. The formula used in this project varies slightly compared to this standard formula.

Sound intensity level $\beta(dB) = 10\log_{10}(I/I_0)$ (1.1)

I = sound intensity in W/m^2

I_0 = reference intensity $10^{-12} W/m^2$ (threshold of hearing)[10]

1.3.2 Physiology of Ear

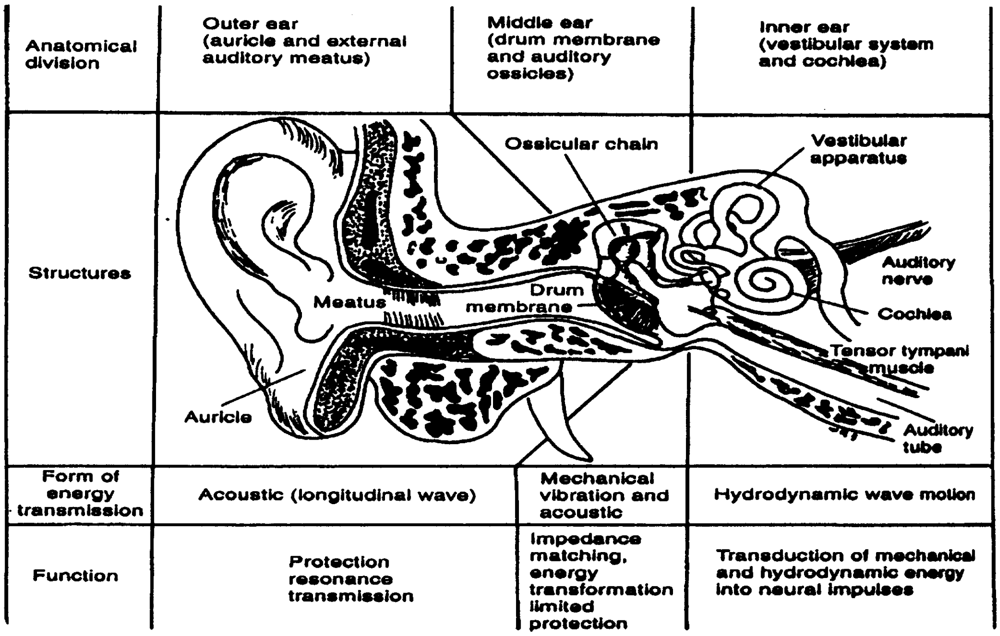


Figure 1.3 Physiology of the ear [12].

The human ear is divided into three parts; outer ear, middle ear and inner ear (figure 1.3). The outer ear consists of the auricle and external auditory meatus. As sound enters the ear, the first structure it encounters is the auricle, which is also known as the pinna of the ear. The auricle is composed mostly of elastic cartilage, which is covered by skin and supported by muscles and ligaments [13]. The external auditory meatus is the connection between the auricle and eardrum. The meatus protects the eardrum from water and any other external dust particles through solid hair and wax secreting glands [13]. The middle ear is composed of a drum membrane and auditory ossicles. The sound exiting the meatus enters the drum membrane causing it to vibrate. The drum membrane is a half curve plate, which vibrates based on the sound frequency. The vibration of the drum plate is then transferred to the ossicles. The ossicles are little bones behind the drum plate, which transfers the vibration from the eardrum to the vestibular apparatus or oval window. The inner ear is composed of the vestibule and the cochlea which converts the mechanical frequency waves into an electrical neural signal. The vestibular system is composed of semicircular canals and vestibule (also known as sacs), which are filled with fluid called endolymph [14]. The cochlea is composed of three parts filled with fluids; two canals and one organ of corti. The canals transmit pressure into the corti, which converts the pressure energy into an electrical neural signal that is transmitted to the brain through the auditory nerve [14]. The auditory nerve then transfers the neural signal to the thalamus where it progresses to the auditory cortex in the temporal lobe of the brain where sound is identified.

CHAPTER 2

METHODOLOGY

This research includes both hardware integration and software development to create a laboratory to study the transmission of light and acoustic energy through a fog medium. Data were compared to the control state, which is the transmission of light and acoustic energy in the same laboratory environment without a fog medium present. The experimental methodology will discuss the mechanical development of the laboratory, the hardware to be used during the experiments, the software developed to integrate instrumentation, the protocol to collect data, and the techniques used for data analysis.

2.1 Experimental Room Setup

An 11 x 11 x 8 feet room was utilized for the audible and visual experiments. The windows were covered with cardboard to prevent external light entering the room. Reflection of light and acoustic energy cause artifacts in experimental data. Black curtains were used to avoid reflection, which can cause artifacts in the visual experimentation data. Acoustic forms, which absorb sound energy, were installed on the walls so that when the sound was deployed through the speaker, sound energy was not reflected throughout the room. Furthermore, the laboratory's doors were sealed with weather strips and the ventilation fans were covered with cardboard to prevent fog leakage in the laboratory. The overall diagram of the laboratory setup is shown in Figure 2.1.

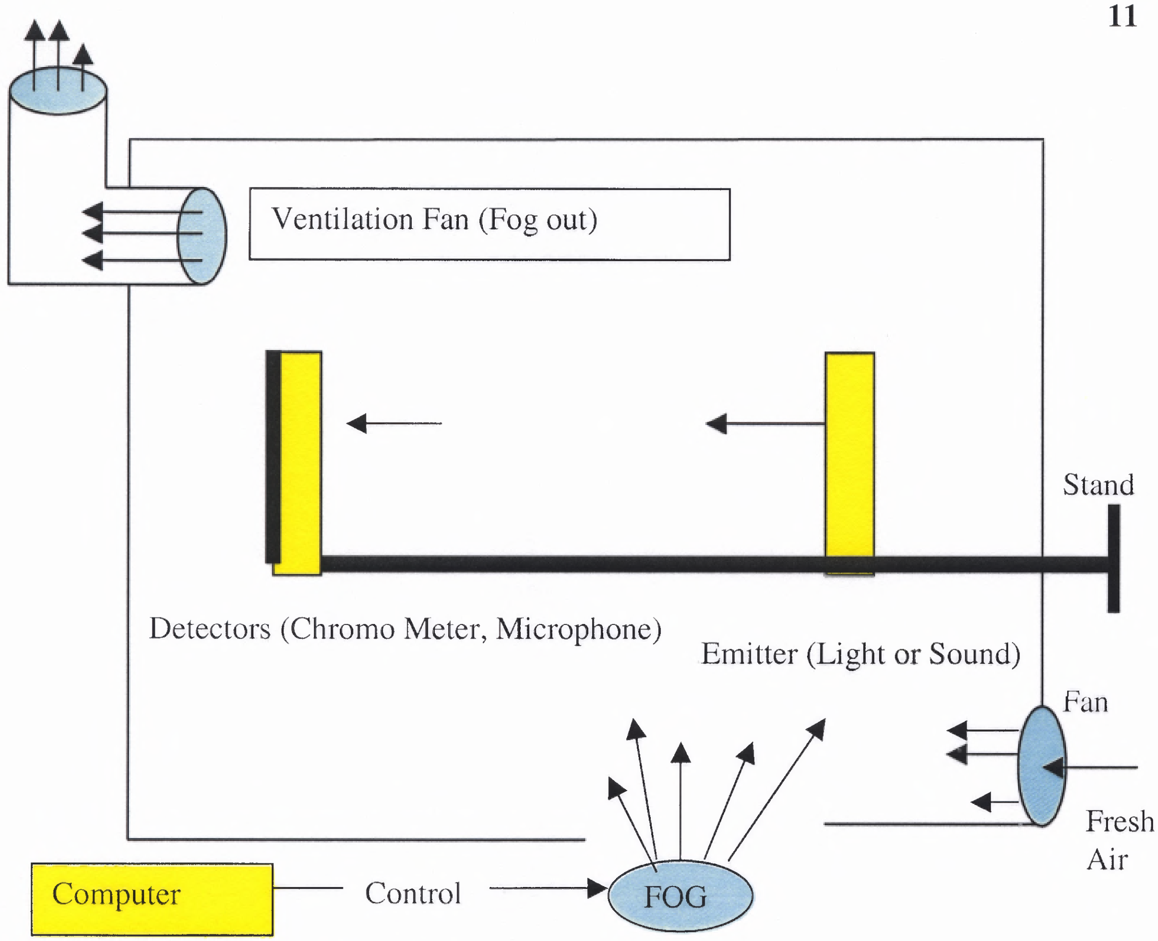


Figure 2.1 Experimental Room Setup.

2.2 Hardware

The key hardware elements used during these experiments were a synthetic fog machine to generate fog, two fans to eliminate fog from the laboratory, A light source to provide output and a chronometer to quantify the amount of light present, speakers to generate sound, and microphones to detect the intensity of sound. A computer controlled the system with custom programs for acquisition of data and control of output

2.2.1 Fog Machine

The synthetic fog machine (SFM) (Model FSS60C, Fog Security System Inc. Winnipeg, Manitoba, Canada) (figure 2.2) can fill a 11 x 11 x 8 foot room with fog in seconds and a person's viewing range declines to one half an inch in a couple of seconds [1]. The SFM distributes fog at a speed of 2250 CFM (cubic feet/minute). Initially, fluid is pumped by a motor in to the heating element of the SFM. The heating element transforms the fluid to its gaseous state. The gas exits the machine through a nozzle. The vapor comes in contact with the air at room temperature and produces an obscurant fog [15].

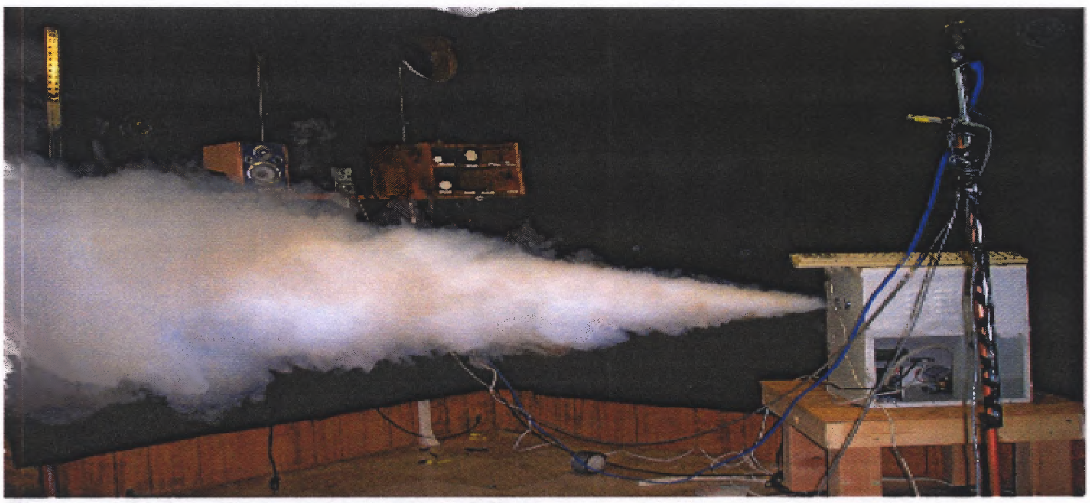


Figure 1.2 Synthetic fog machine (SFM).

The fluid dissipated from the SFM consists of propylene glycol, glycerol and distilled water. Glycol ($C_2H_6O_2$) is a clear, odorless, tasteless, slightly viscous liquid. Human exposure to high concentrations of glycol can result in nausea, slurred speech, convulsions, disorientation, as well as heart and kidney problems [16]. Glycol may cause transitory stinging of the skin and tearing in the eyes. " Propylene Glycol causes a substantial number of reactions and was a primary irritant to the skin in low levels of concentrations."[16]. Glycerol (C3H5 $(OH)_3$) also called trihydric alcohol is an odorless, colorless, sweet tasting syrupy liquid. Glycerol causes nausea, headache, diarrhea, eye and skin irritation, and kidney injury to humans if exposed to high concentrations [16]. The concentration level of glycerol and glycol, in the liquid used for this research, is non-hazardous and it has been investigated by OSHA (Occupational Safety and Health Administration).

2.2.2 Exhaust System

Two fans (model number. VAF - 3000 Americ Corp, CA) were installed in the room, one to pull air from the room and another to blow fresh air into the experiment room. The fans were used to evacuate the fog as quickly as possible to protect potential human subjects.

Figure 2.3 Fan to evacuate the fog.

Figure 2.4 Fan to blow fresh air.

The fan can evacuate fog in 8 - 10 seconds since it has 2091 CFM (cubic feet / minute) and the cubic feet of the room is 968 (11x11x8) [23]. The fans have a diameter of 1 foot and a length of 2 feet. Once the fans were installed, the next step was to have a sophisticated ventilation system to evacuate the fog out to the ceiling.

Figure 2.5 Exhaust System.

For this ventilation system (Figure 2.5), aluminum pipes of 12 feet diameter, a rain cap, wall strips, and sealer wax were used to prevent water from entering the room.

2.2.3 Audible System

The Audible system is composed of two parts; the speaker (Model MA–10D, Edirol manufacturing company, Bellingham, WA) used to transmit the audible sound frequencies (Figure 2.9) and the microphone (model number is 1947247, Bruel and Kjaer, Norcross, Georgia) (Figure 2.6) was used to transduce the audible sound. A micrometer (type 5935 - Figure 2.7) was used to connect the microphone to an Analog to Digital (A/D) card (BNC 2090- Figure 2.8).

Figure 2.6 Microphones.

Figure 2.7 Micrometer.

As shown in Figure 2.7, the micrometer receives the input signal from the microphone and transmits that signal to the A/D card when it is digitized via the DAQ card(PCI-MIO-6E4, National Instruments).

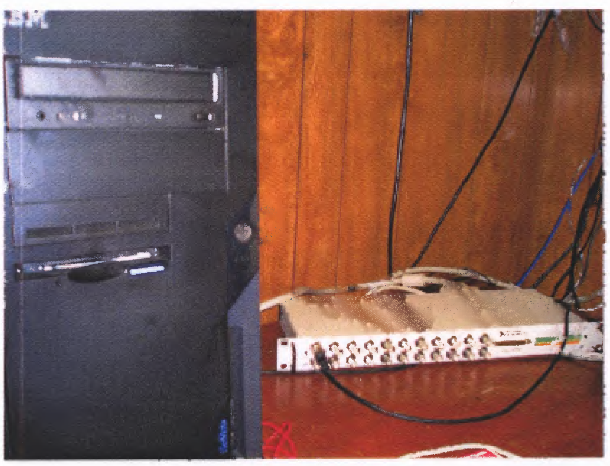


Figure 2.8 Analog / Digital conversion.

Figure 2.9 Speaker for sound transmission.

The formula (2.1) used in this project has been provided by Bruel & Kjaer, the company which manufactures the microphone [11]. Every microphone is different based on their capacity of detecting various intensity levels of the sound. The microphone used in this project is a cutting edge device manufactured by Bruel & Kjaer. The formula used in this project for the detection of the sound intensity is;

dB = $[\log[(Vrms/So)/(20\mu) * 20]$ - Gain Setting of amplifier(constant) (2.1)

Vrms = Signal transmitted in the microphone

So = Open-circuit Sensitivity (Amplification Constant)

Gain Setting = Microphone setting from 10db – 60db (External amplification source) [11].

2.2.4 Visual System

The visual system is made up of a Chromo meter (light receptor) and Mini Martin Mac(light source). A Chromo meter (model number is G920934 – type CL-200 Ramsey, New Jersey) was used for measuring the light signals (figure 2.10) CL-200 has a detachable head receptor (figure 2.11), which helps the operator to collect data from other locations.

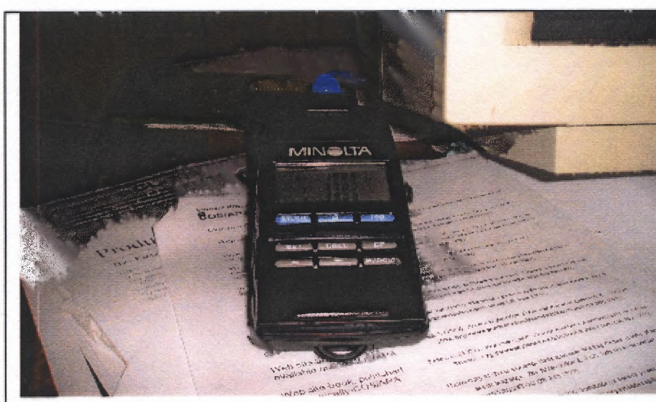


Figure 2.10 Chromo meter.

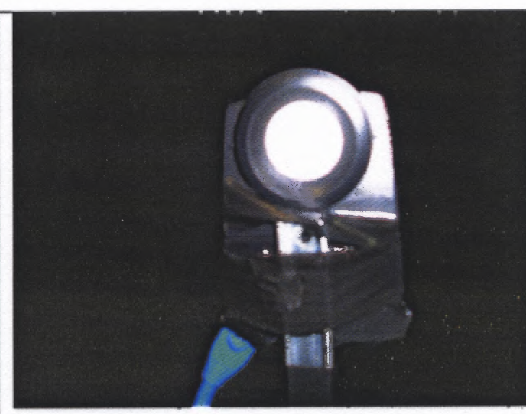


Figure 2.11 Receptor head of chromo meter.

The light receptor head was placed in the experiment room and data recording was performed in the room next to it. The Martin Mini Mac (MMM) was used for transmitting different colors of light it is an automated single-armed moving head spotlight (Figure 2.12).

Figure 2.12 Mini Martin Mac [17].

The light source has 12 diachronic gobos (gobos are round glass slides of different colors housed inside the machine), high-speed shutter, 540°of pan by 270° of tilt, 17° beam angle with manually adjustable focus, and 3-digit LED control panel, and switch-selectable powers supply settings. The microphone and CL-200 receptor head were mounted on the top of an L-shape stand (9'x5') inside the experimental room, where the operator has control over the distance that the microphone and CL-200 receptor head is located from the light and sound emitters from the adjacent room (Figure 2.13).

Figure 2.13 L shape stand connecting experimental room to the next room.

One end of the stand was outside the experimental room and another was inside the room to uphold the receivers of light and sound. The purpose of the stand is to adjust the distance of the light and sound meters during experimentation. For example, if the data are collected at distance of 1 foot then the operator does not have to enter the experiment room to move the light and sound meters to another distance. He or she can change the distance of the meter in the experimentation room from the operation and data acquisition room. Another advantage of the stand is it facilitates the collection of accurate data because each time the experimentation room is opened, the fog is dissipated which can create artifacts in the data between the receiver and the source.

2.3 Software

There were three main software programs used in the project. Lab-VIEW 7.0 (manufactured by National Instruments), Cool Edit 2000, and Easy Stand Alone (manufactured by Elation professional 2000). Lab VIEW 7.0 and Cool Edit 2000 were used for sound experimentation and Easy Stand alone was used for the light experimentation.

2.3.1 Introduction to Lab View Programming

Part of the thesis required a program to be developed which could play audible sinusoidal frequencies (ranging from 50 Hz to 20000 Hz) while simultaneously recording the sound waves through a microphone, converting the measured signal to its corresponding decibel level and storing the data to a file.

Laboratory Virtual Instrumentation Engineering Workbench LabVIEW (Version 7, National Instruments, Austin, TX) was chosen for sound recording and processing applications. LabVIEW is a graphical programming environment based on the concept of data flow programming. This programming paradigm has been widely used for data acquisition and instrument control software. LabVIEW programs were used by astronauts in the 1993 Columbia space shuttle mission to study motion sickness [18]. It was also used by researchers at the University of Maryland for an application, which helps physicians to perform cardio thoracic research [19]. This software package contains two parts, a front panel and block diagram. The front panel is the user interface where the program outputs its signals and the operator can monitor multiple input and output signals. On the front panel, the operator can view the program's performance. The block diagram contains the programming code written by the user, which connects different sub routines to perform various functions such as emitting sound, digitizing data, the configuration of the system, the initialization and execution of data acquisition, storing data to a file and many other functions. LabVIEW provides the capability of different graphs and charts, which facilitates analysis of the data [19 - 20].

2.3.2 Introduction to Cool Edit

Cool Edit (Version 2000, Syntrillium) was used in this project to create sound frequencies starting from 50 Hz to 20,000 Hz. There were a total of thirty-seven sinusoidal waveforms created using Cool Edit software each of a five second duration. Cool Edit is an audio editing software tool, which allows the operator to create and record different sound waves and store them in different formats. With this software, an operator can create ultrasound, infrasound or audible sounds. The user can also define the type of wave function such as; sine, triangle, square, sawtooth etc. as well as the duration of the signal and the sampling rate of the sound wave. [21] The format for this project is the Microsoft "wav" standard. How the sound is played will be discussed in the data acquisition Section 3.3.

2.3.3 Easy Stand Alone

Easy Stand Alone (ESA) software (Elation, Los Angeles, CA) has been designed for users mainly seeking complete ease of use and elaborated so as to offer full control over the paradigm. ESA is widely used in theaters, musical events, programs, and stage shows. ESA software was used to provide different color light stimuli (red, blue, green, orange, red, purple etc.) through the light source which is further described in section 2.1.2 [21].

The ESA has four main steps; first is to setup the appropriate channels for the light in which computer sets the port number to which device is connected. The second step is to create scenes (macros) in which the operator can choose the colors of the light, set the angle of the light emitter, and many other options, which facilitate in creating the best light shows. The third step is to use the software in "live mode" which allows the operator to control the lights and make changes, in the setting of the light, at anytime. Finally, the stand alone mode in which the operator can store many scenes, which are already created, and change the color of the lights through the USB box (external storage device – Figure 2.14).

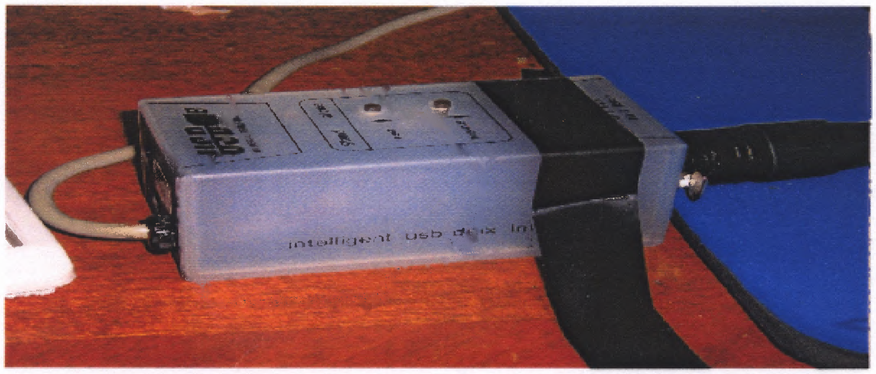


Figure 2.14 Intelligent USB box.

In creating scenes, the operator can program a number of steps. Each of the steps has a fade time and waiting time, which can be set. By creating several steps in sequence, the user was able to control different color scenes in a loop. Each scene can include up to 1,000 steps. However, the scene for this application was made up of 6 steps; shutter (open-close), color, gobo (constant), rotate gobo, pan (move light horizontally), tilt (move light source vertically). During the next step using the software in live mode with a computer, the lights can be controlled through the computer. Here the operator has full control over the functions provided such as; "previous" and "next" scene, play cycle (plays scene in cycle similar to a loop), auto function in which the channel works automatically on the current scene and the manual cursor is also de-activated. Finally in the stand-alone mode, light can be controlled without computer. All the scenes were stored in to the external storage box (USB – Figure 2.14), which has "previous", and "next" buttons on the USB box. This mode is very useful and it facilitates data acquisition from the CL-200(chromo meter-light meter) [21].

2.4 Data Acquisition

Data were automatically acquired, using Lab VIEW software, in the auditory experiments. Sound waves were played, recorded, and saved in to a file, automatically. The data recorded by the CL-200 were manually entered into Excel files by the author for the light experiments. Both visual and auditory experiments used excel spreadsheets for the storage of the data. Excel was also used for generating graphs for analysis of the data.

2.4.1 Auditory system

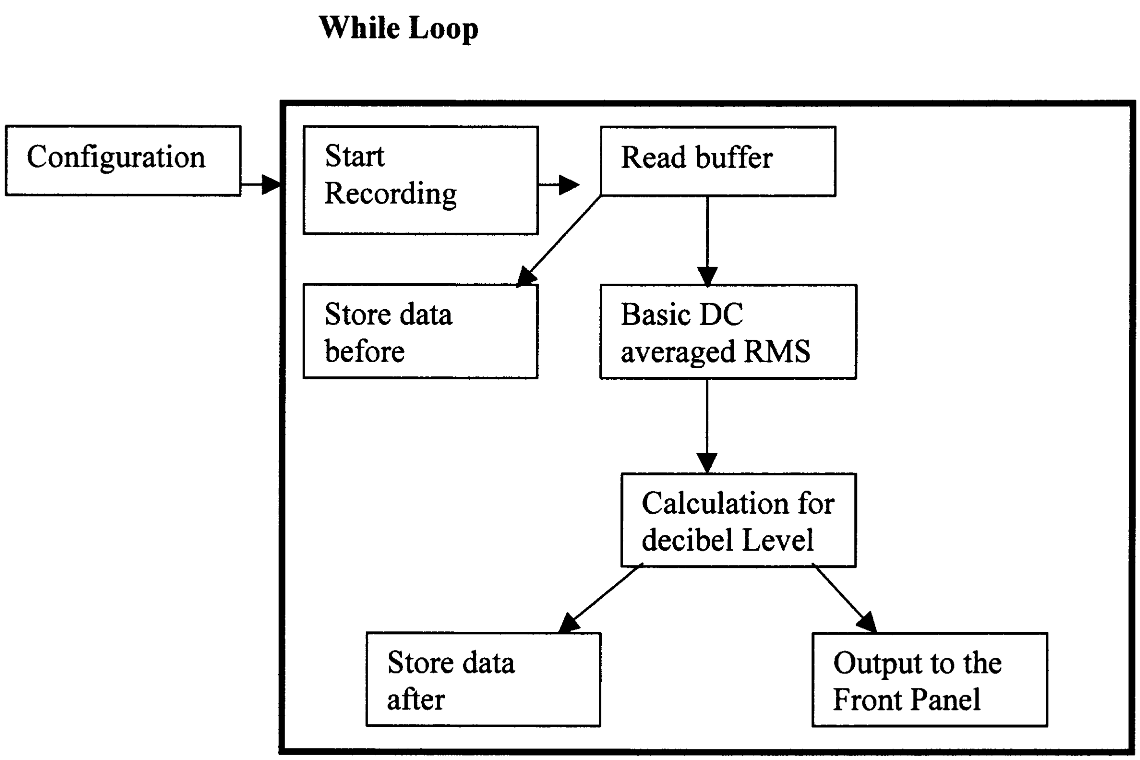


Figure 2.15 Block Diagram of the Software Development of the sound experiment

The Figure 2.15 shows the block diagram of the software development needed for the sound propagation in to an ambient air and synthetic fog medium. The program first configures the system with elements such as channel number; device number and buffer channel number specifies which of the analog input channels will be used; in this research the channel used was 0. The device number is the device number assigned to the DAQ device during configuration, which in this research is1. The buffer size is the total number of scans you want the buffer to hold, in this research the buffer size was 220100 because each scan was for 44000 then the five scans were 220000. In other words, 220000 is the total number of scans used in the experiment and the buffer size was set to 220100 which is more than enough to hold the data acquired from the experiment. The start VI begins the recording with the scan rate of 44000 scans / sec and the number of scans to acquire is 220000 during a 5 second duration. The scan rate is the number of scans to acquire which is equivalent to the sampling rate per channel. A scan rate of 44000 scans /sec was chosen because the maximum frequency of sound was 20000 Hz and according to the sampling theorem, the sampling rate should be at least two times or greater than the maximum frequency to eliminate aliasing. When aliasing occurs, the original signal can not be recovered [18]. The "number of scans" to acquire is the total number of scans LabVIEW acquires before the acquisition completes. If the sampling rate is 44000 for one second then to acquire five seconds of data, the number of scans to acquire was set to 220000 which is 5 times 44000. As soon as the "Play Sound" VI is initiated the "Start VI" will begin to record and digitize the signals (Appendix B). The "Play Sound" VI receives its input from the case structure of 38 different frequencies starting from 50 Hz to 20,000 Hz. The Play VI, Start VI , and Read VI are within the while loop and the case structure sends sound files according to the while loop count. Then the "Read VI" reads data from a buffered data acquisition. Acquired data is stored in a text file and also viewed on the front panel through graphs. The "Basic DC/ RMS

VI" receives an array of waveforms, applies a window to the signal, and averages the DC and RMS values calculated from the windowed signal (Appendix B). The averaged RMS value is used in the conversion equation to measure the signal in decibel. The formula used for the decibel level calculation is

dB = [log[(Vrms/So)/(20μ) *20] - Gain Setting of amplifier(constant) (2.2)

Vrms = Signal coming in from the microphone

So = Open-circuit Sensitivity(Amplification Constant)

Gain Setting = Microphone set from 10db – 60db(External amplification source)

Calculated dB values are stored in a text file and also are displayed on the front panel of the lab VIEW program as a numeric array.

2.4.2 Visual System

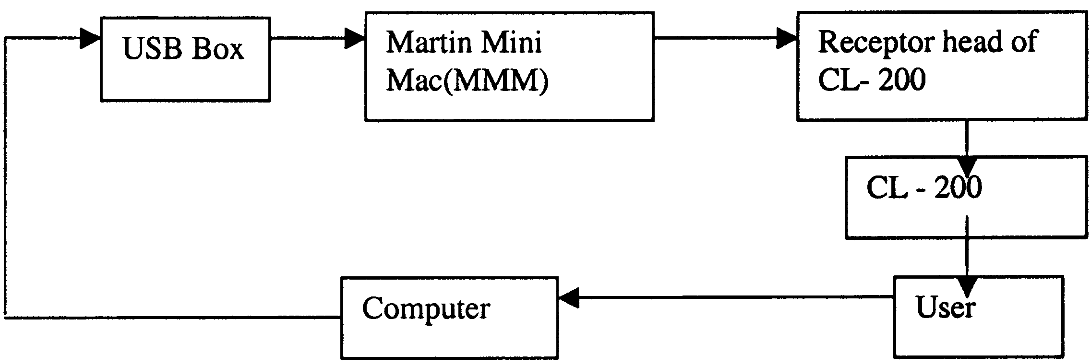


Figure 2.16 Block diagram of the Light Experimentation

The light experimentation did not need as much data manipulation compared to the auditory experiments. There were eight scenes created by the author in the Easy Stand Alone, one for each color to be analyzed. These scenes were stored in the external box called the USB box (the storage device for the scenes). The USB box transfers different color scenes to the Martin Mini Mac. The Martin Mini Mac transmitted the color defined in the particular scene of interest. Light was than detected by the receptor head of the CL-200 (light meter). The light intensity was displayed on the CL-200 meter in numeric form as luminescence (Lux). The intensity measured in lux was stored in an excel file by the author for further analysis of the data.

2.5 Data Analysis

The recorded data for the light and sound experiments were synchronized and analyzed by preparing various graphs plotting different parameters. Analysis of the data yields insights as to the implication of a fog medium on light and sound transmission.

2.5.1 Light

The luminescence, light intensity in fog and air environment was saved in an Excel file. The collected data have three different parameters; distance (in inches), density of fog (the amount of time the fog machine dissipated fog), and colors (in wavelengths). To acquire a better understanding, data were divided into three different sheets in the Excel workbook; data organized by color, density, and distance. There were eight different colors of light used in this research project. Among the three parameters studied, distance and density of fog were known; however, the wavelength of the light color was unknown. Mini Martin Mac, the company that makes the light source used in the project, provided the wavelength of the colors emitted. Using three known parameters the graphs were developed. Data were collected by the Chromo meter (light meter) which had a high sensitivity curve. The sophisticated Chromo meter used in the project has a very high relative sensitivity curve versus wavelength (λ) (figure 2.17), which means the intensity of the light measure is not the actual intensity. The Chromo meter has a sensitivity curve because it must respond to the light as the CIE (Commission Internationale de l'Eclairage or International Commission on Illumination) standard observer. In other words, the spectral response of the photometer, chromo meter, must follow the CIE Standard Luminosity Function V_{λ} curve. The sensor of the photometer is critical to the accurate performance of the photometer. Data were divided by its sensitivity to obtain accurate measurements of the original color of the light.

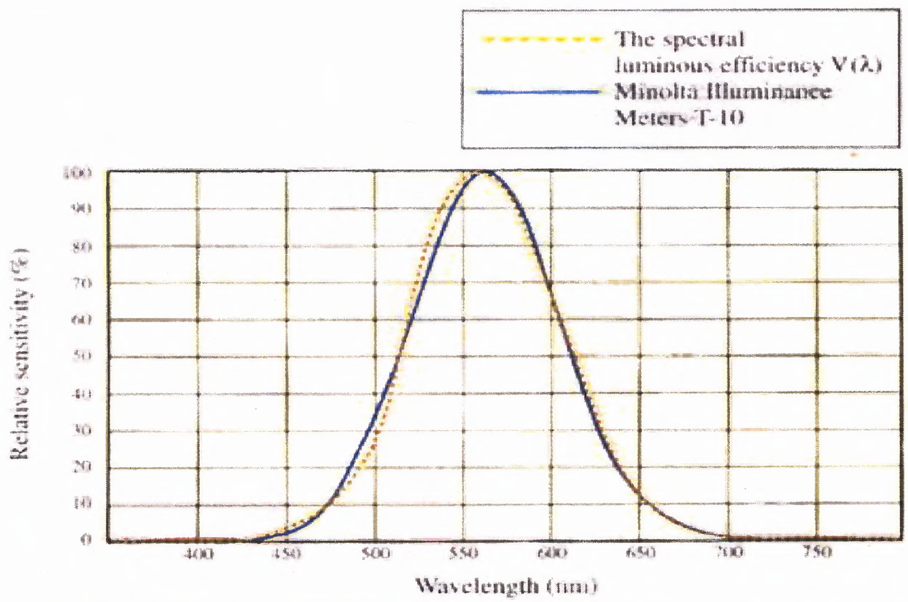
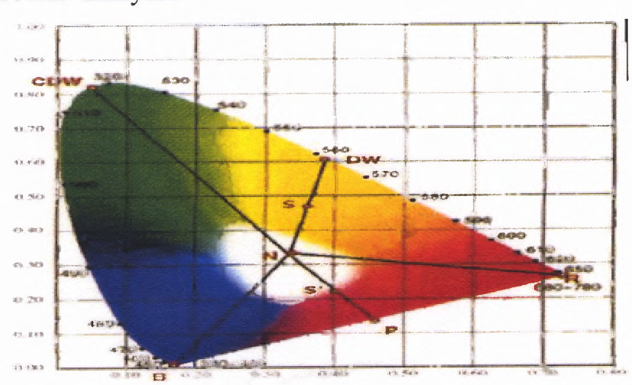


Figure 2.17 Relative spectral analysis.



Fiure 2.18 Helmholtz coordinates.

Normalization of the data was necessary to view the actual data without any sensitivity. In other words, the receptor head of the light meter is sensitive differently to the different frequencies of the light. The sensitivity curve is not flat, so the calibration of the light sensor was necessary to compensate the sensor's sensitivity. Each color's wavelength was determined by x and y coordinates, given by the chromo meter, and the actual wavelengths were obtained using the Helmholtz coordinate (provided by Minolta corp. (figure 2.18). Helmholtz coordinate system is two-dimensional graphical_representation of the light intensity in wavelength. Therefore, each color was divided by its sensitivity of the meter and each color's sensitivity in percentage of the wavelength in nanometers (nm) is listed below.

Table 2.1 Original Wavelengths of the Light

30%	RED	630nm
65%	ORANGE	590nm
99%	YELLOW	575nm
32%	GREEN	500nm
12%	PURPLE	485nm
6%	BLUE	470nm

For the data that was organized based on color, data were grouped by the colors; red, orange, yellow, green, purple, blue, and white. Then 2D and 3D graphs were created using the wavelength, distance, and density of fog in seconds. For the data that were organized based on distance, between the transmitter and the receiver, were quantified as; 2, 3, 4, 5, 6, 7, and 8 feet. For the data that were organized by the density of fog, the amount of fog created was quantified for 0 sec (no fog), 2, 4, 6, 8, and 10 seconds of fog production.

2.5.2 Sound

In the sound experiments, data were collected automatically by the LabVIEW program developed as part of this research and stored in a excel file. There were three parameters stored to the data file; distance the microphone was placed from the transmitter (feet), density of fog measured as the amount of fog produced (seconds), and the frequency of the sounds measured in hertz (Hz). Thirty-eight sound files, each five seconds in length, were created as part of this research using the Cool Edit software. Each of the thirty eight files were for a different frequency where the following frequencies were quantified: 50 , 100,150, 200, 250, 300, 350, 400, 450, 500, 550, 600, 650, 700, 750, 800, 850, 900, 1000, 2000, 3000, 4000, 5000, 6000, 7000, 8000, 9000, 10000, 11000, 12000, 13000, 14000, 15000, 16000, 17000, 18000, 19000, 20,000 Hertz. Graphs were created by plotting distance as a function of frequency and fog density where the distance is denoted as the space between the microphone and the speaker for the following distances: 1, 2, 3, 4, 5, 6, 7, 8 feet. The density of fog quantified was defined as the amount of time (in seconds) that the fog machine dissipated fog where the densities investigated were 0 sec(no fog), 10 sec, 20 sec, 30 sec, and 40 sec. Unlike the light experiments, the sound experiments did not amplify the signal, thus no manipulation of the data were necessary. Figure 2.19

shows the frequency response of the preamplifier at low and high frequencies of the microphone.

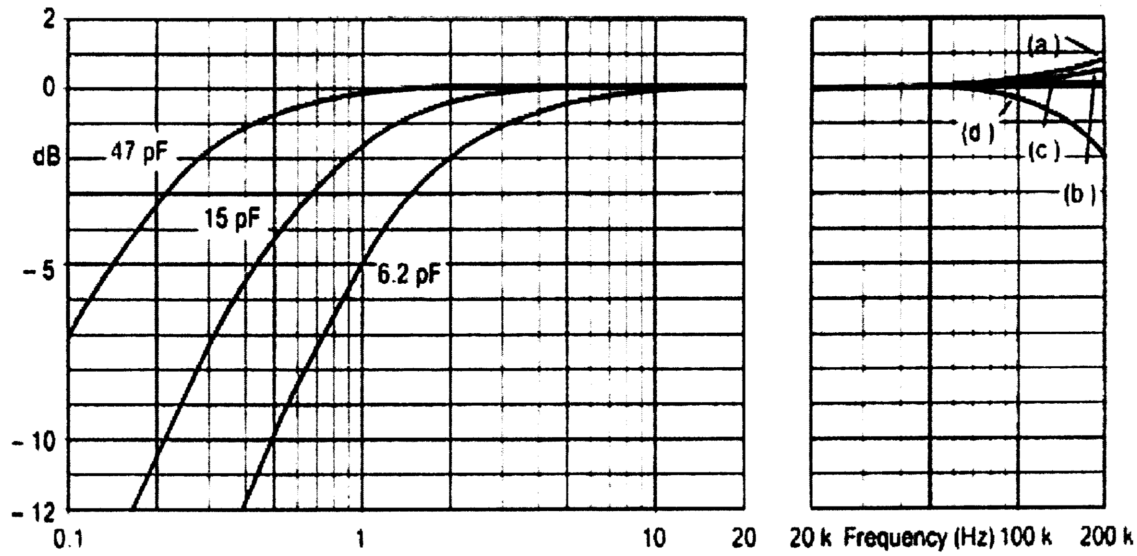


Figure 2.19 Microphone frequency response chart.

As per Figure 2.19, the microphone has a flat frequency response between 20Hz and 20kHz. Therefore there is no amplification or attenuation factor to be considered when analyzing the data. As a validation of the system, the collected data were also compared with the data collected from the sound meter (manufactured by Radio Shack model number 33-2050) to determine if the system, developed through this research, was accurate. The data from the two systems, signals recorded using the Radio Shack sound meter and signals measured from the system developed by this research, will be described in Chapter 3.

CHAPTER 3

RESULTS

The two dimension and three dimension graphs were obtained from the light and sound experiments. Given the amount of data collected, data reduction was necessary to interpret results, which was facilitated with graphs. Section 3.1 shows the results of the light experiments and section 3.2 discusses the results of the sound experiments.

3.1 Light Experiment Results

Data from the light experiment were collected and then normalized with respect to the sensitivity of the chromo meter. Section 3.1.1 shows the graphs of actual data without calibration and sub Section 3.1.2 shows the normalized data grouped by colors. The light data were further analyzed in section 3.1.2.1, and 3.1.2.2 by dividing the results into two subcategories; data by density of the fog, and data by distance the light meter was placed from the transmitter. In both subcategories, data by density and data by distance, normalized data were used for graphical analysis. The calibration of the data was done using the sensitivity chart provided by Minolta Corp., the company which manufactures the chromo meter (light meter). The sensitivity chart is displayed in Section 3.2. Sound data did not have calibration to consider, since the microphone used in the experiment has flat frequency response curve in the audible frequencies that were investigated in this research. The frequency response curve for the microphone is provided in Section 3.2.

3.1.1 Light Actual Results

There were seven colors tested in the light experiment; red, orange, yellow, green, purple, blue, and white. The graphs of these colors have two things in common; 1) for each wavelength the intensity of light is inversely proportionally to the production of fog, and 2) the distance the chromo meter receptor head was placed from the transmitter was inversely proportional to the production levels of fog.

Table 3.1 Actual Intensity of Red Light Collected at Different Distance and Fog Production Level

Red Light Data	2ft	3ft	4ft	5ft	6ft	7ft	8ft
0 SEC NO FOG	4940	2117	1022	581	360	266	220
2 SEC	2207	1002	617	401	290	218	187
4 SEC	543	396	193	127	96	86	74
6 SEC	365	164	102	86	65	59	51
8 SEC	108	49	25	16	14	13	12
10 SEC	56	27	13	8	5	4	3

Table 3.2 Intensity of Orange Light at Different Distance and Fog Production Level

Orange Light Data	2ft	3ft	4ft	5ft	6ft	7ft	8ft
0 SEC NO FOG	42170	17850	8770	5136	3610	2410	1969
2 SEC	21280	10560	5434	3520	2636	1811	1577
4 SEC	8440	3949	1999	1437	1006	849	765
6 SEC	3312	2062	1322	866	686	583	525
8 SEC	834	406	286	173	152	129	109
10 SEC	545	250	130	74	57	38	31

Table 3.3 Intensity of Yellow Light at Different Distance and Production Level of Fog

Yellow Light Data	2ft	3ft	4ft	5ft	6ft	7ft	8ft
0 SEC NO FOG	89220	37580	18550	10570	6628	4909	4017
2 SEC	31950	18160	10670	6906	5071	3841	3161
4 SEC	9320	6004	3431	2327	1884	1593	1413
6 SEC	5565	3082	2142	1530	1203	1029	1008
8 SEC	1491	801	473	313	292	249	205
10 SEC	1189	517	246	140	94	72	58

Table 3.4 Intensity of Green Light at Different Distance and Production Level of Fog

Green Light	2ft	3ft	4ft	5ft	6ft	7ft	8ft
0 SEC NO FOG	12440	5166	2461	1432	928	687	556
2 SEC	4804	2197	1319	883	666	506	437
4 SEC	1173	883	460	303	254	222	192
6 SEC	824	412	265	219	170	138	132
8 SEC	265	106	65	44	40	34	28
10 SEC	157	69	34	21	15	11	9

Table 3.5 Intensity of Purple Light in Lux at Varying Distance and Production of Fog

Purple Light	2ft	3ft	4ft	5ft	6ft	7ft	8ft
0 SEC NO FOG	10080	4230	2065	1174	842	560	456
2 SEC	5060	2367	1306	823	607	425	360
4 SEC	1769	946	445	329	257	210	174
6 SEC	673	554	319	206	170	134	124
8 SEC	251	106	72	43	40	32	27
10 SEC	140	64	33	19	15	10	8

Table 3.6 Intensity of Blue Light in Lux at Varying Distance and Production of Fog

Blue Light	2ft	3ft	4ft	5ft	6ft	7ft	8ft
0 SEC NO FOG	5840	1970	950	545	352	258	210
2 SEC	2640	1140	610	372	275	210	171
4 SEC	730	369	183	140	105	85	74
6 SEC	290	197	131	85	70	53	51
8 SEC	114	41	28	18	16	14	12
10 SEC	71	26	14	8	6	4	3

Table 3.6 Intensity of White Light in Lux at Varying Distance and Production of Fog

White light	2ft	3ft	4ft	5ft	6ft	7ft	8ft
0 SEC NO FOG	94540	39780	19430	11340	7127	5233	4291
2 SEC	36140	18750	11130	8626	6081	3963	2886
4 SEC	13100	6342	4978	2641	1970	1679	1541
6 SEC	8642	3178	2520	1916	1324	1096	1068
8 SEC	3478	932	587	397	366	287	176
10 SEC	2039	653	237	175	96	71	53

Each table contains the data used in the graphs (Figure 3.1 to 3.15) below. Plotting the table data in graphs facilitated interpretation of the data.

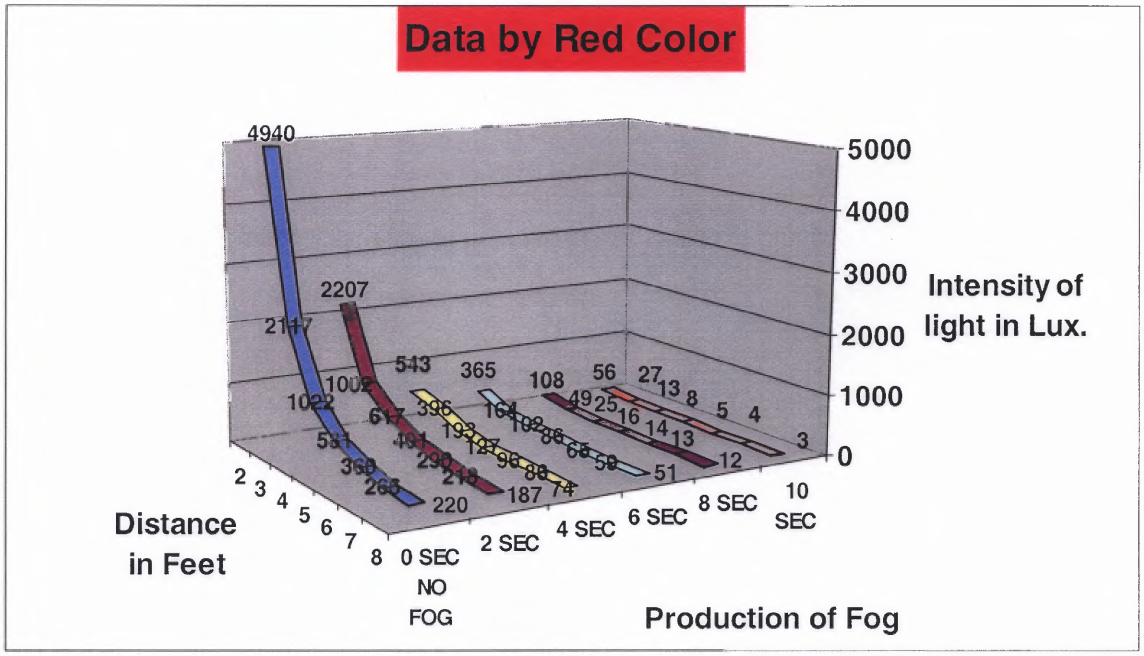


Figure 3.1 Data by red color is acquired by using three parameters distance the microphone is placed from the transmitted (feet), fog production quantified by the number of seconds the fog machine dissipated synthetic fog, and intensity of the light measured in Lux. Intensity of each color is shown respectively as a function of distance and fog production in seconds.

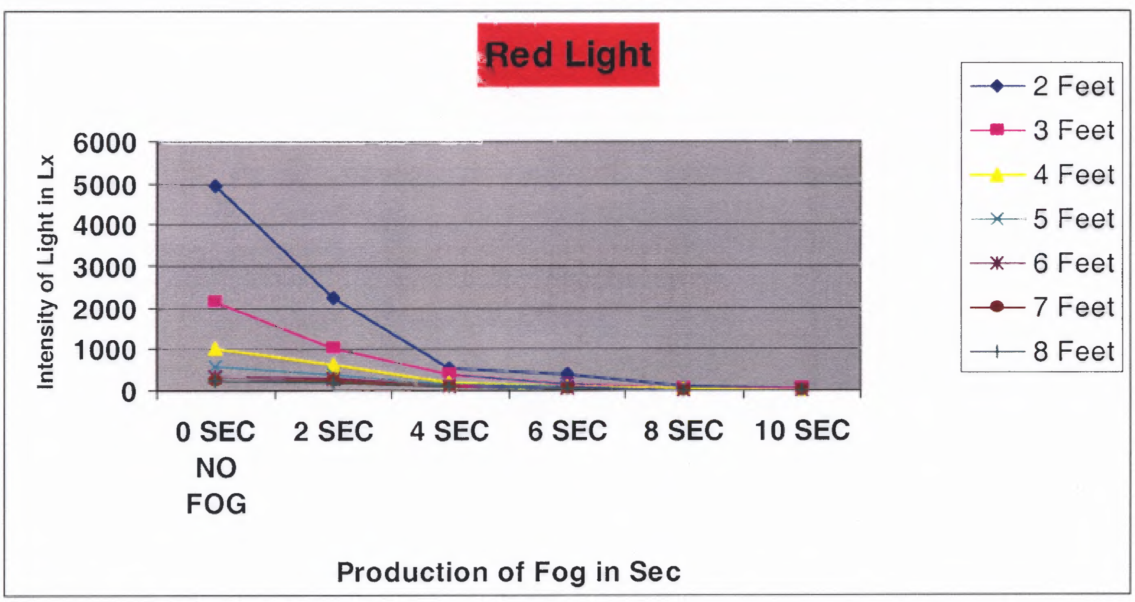


Figure 3.2 Two dimensional graph of red light was analyzed from no fog(0 sec) to 10 seconds of fog production with distance difference between the source of light(MMM) and the receiver head of the chromo meter.

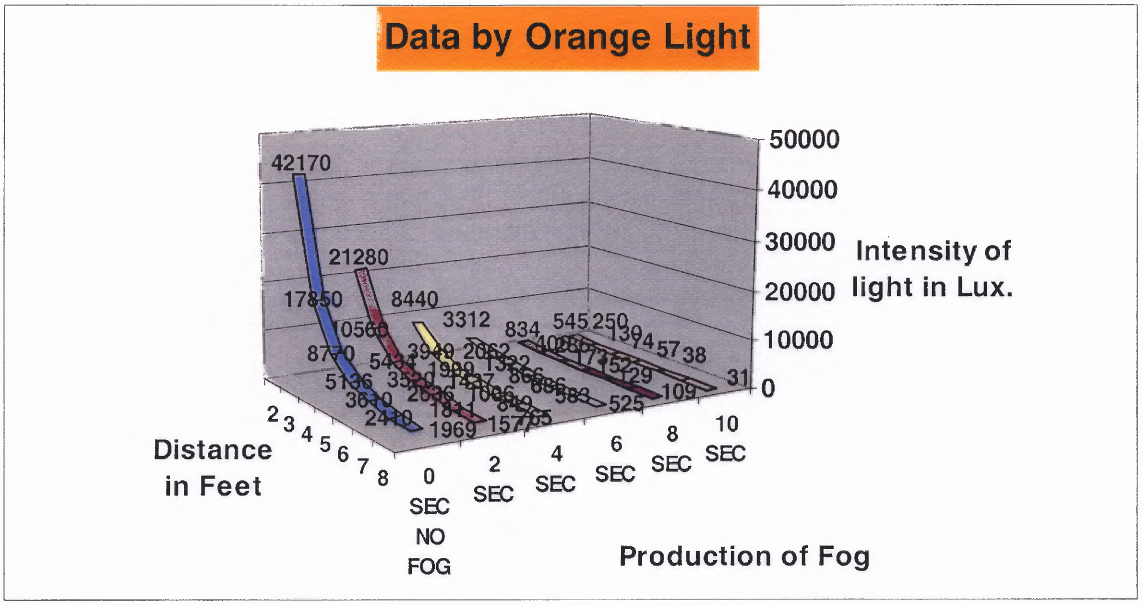


Figure 3.3 Orange light quantified in an environment with no fog and with fog production starting from 2 second to 10 seconds of fog production. This graph shows the intensity of orange light with respect to the distance difference between the source and the receiver of the light, and fog production.

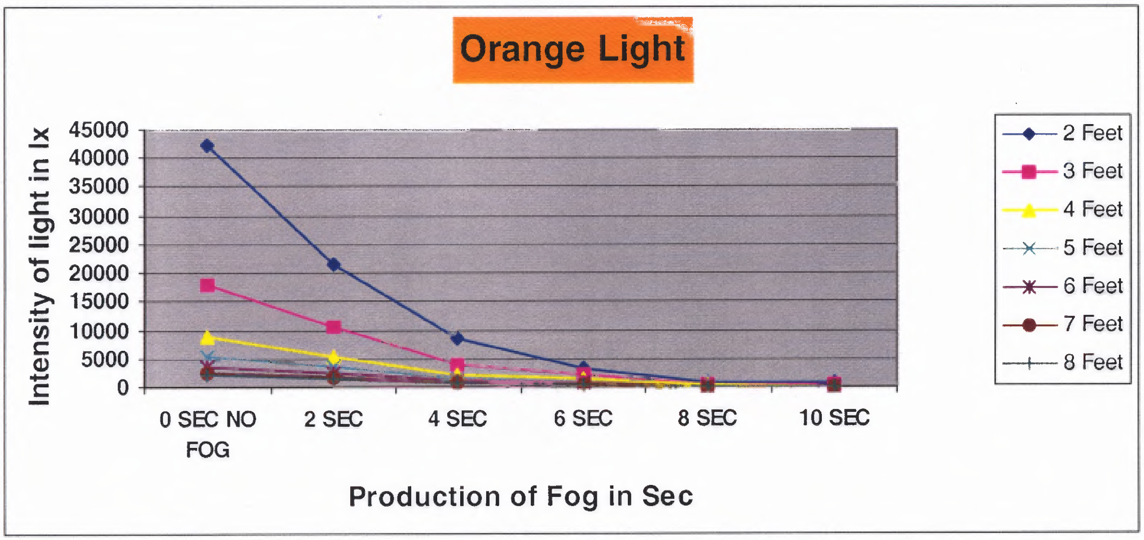


Figure 3.4 The intensity of orange light as a function of fog production. Each line represents the distance from the source of light to the receiver sensor of light.

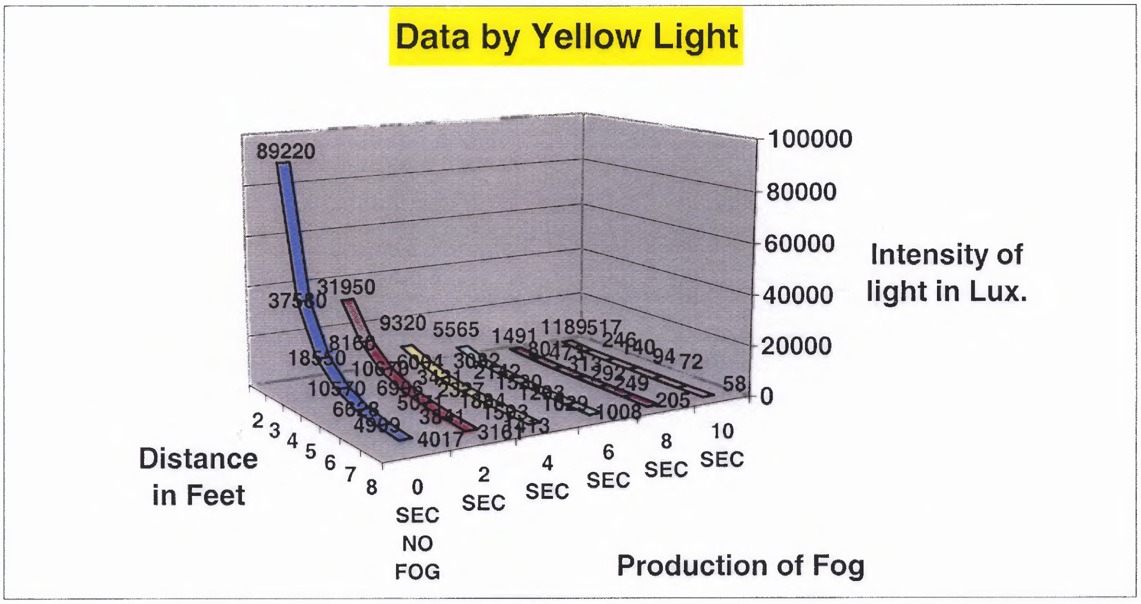


Figure 3.5 Intensity of light at each production level of fog and distance for the yellow color.

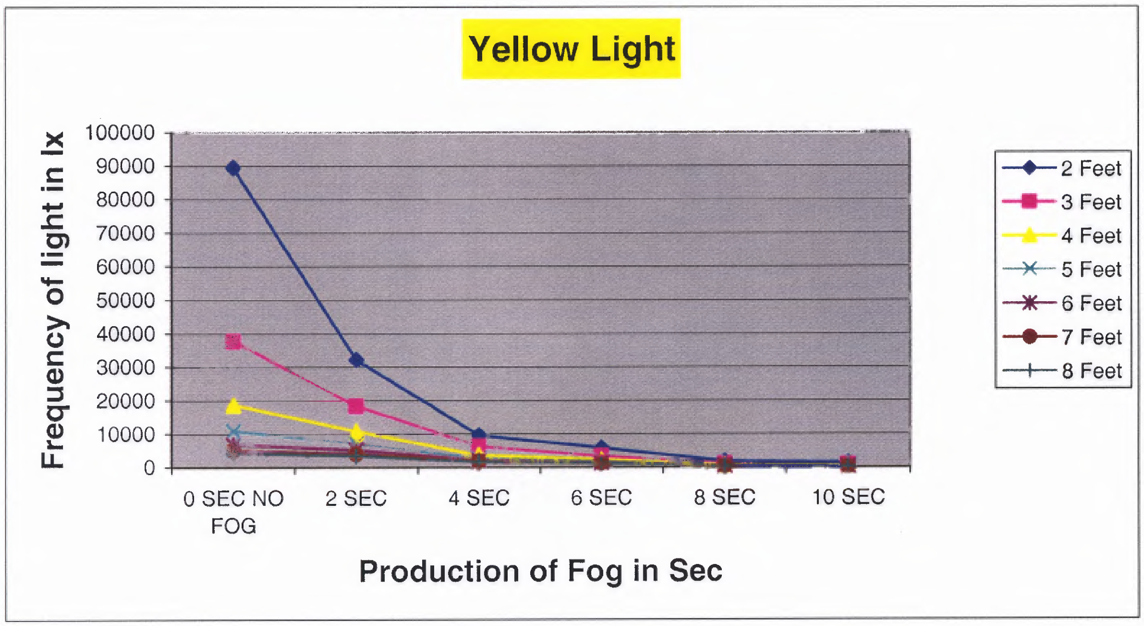


Figure 3.6 Two dimensional graphical analysis of yellow light.

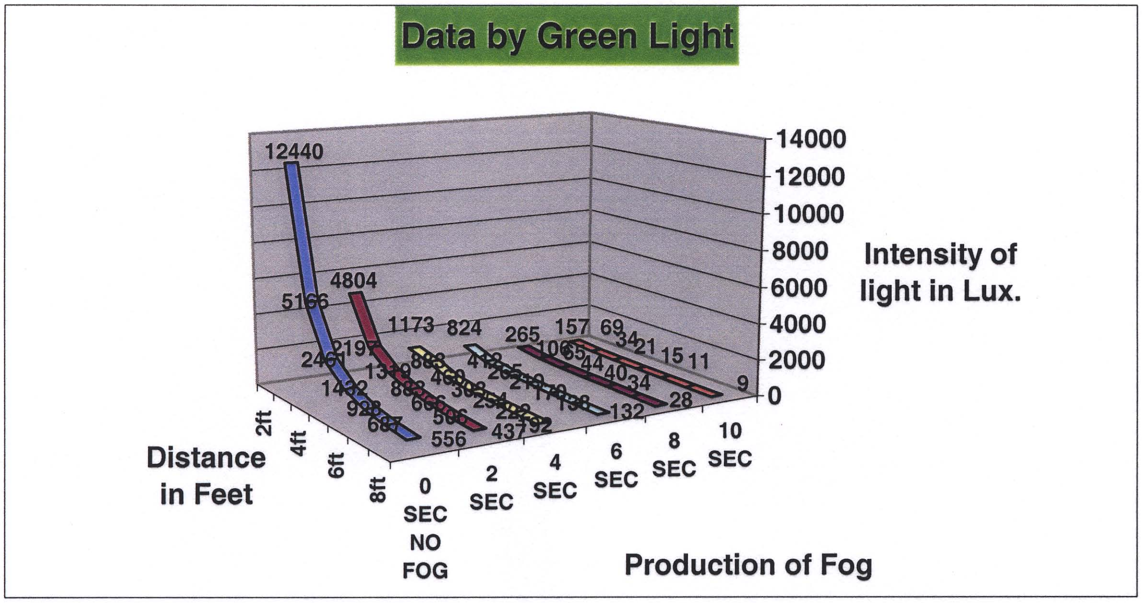


Figure 3.7 Intensity of green light in fog and varying production of fog at different distances.

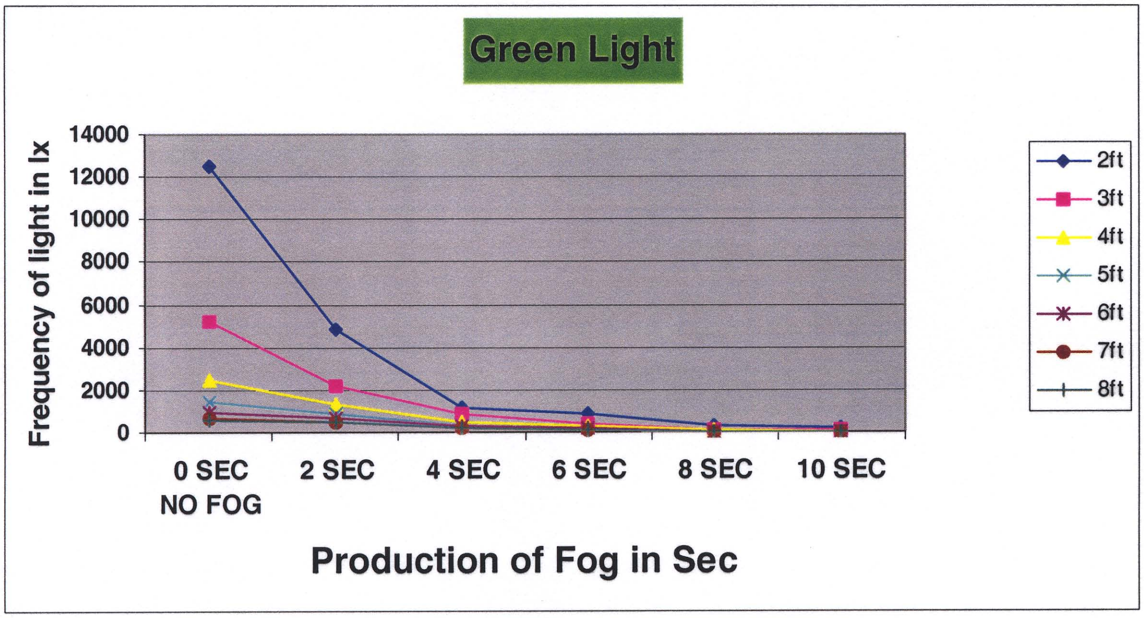


Figure 3.8 Intensity of green light is inversely proportional to production of fog.

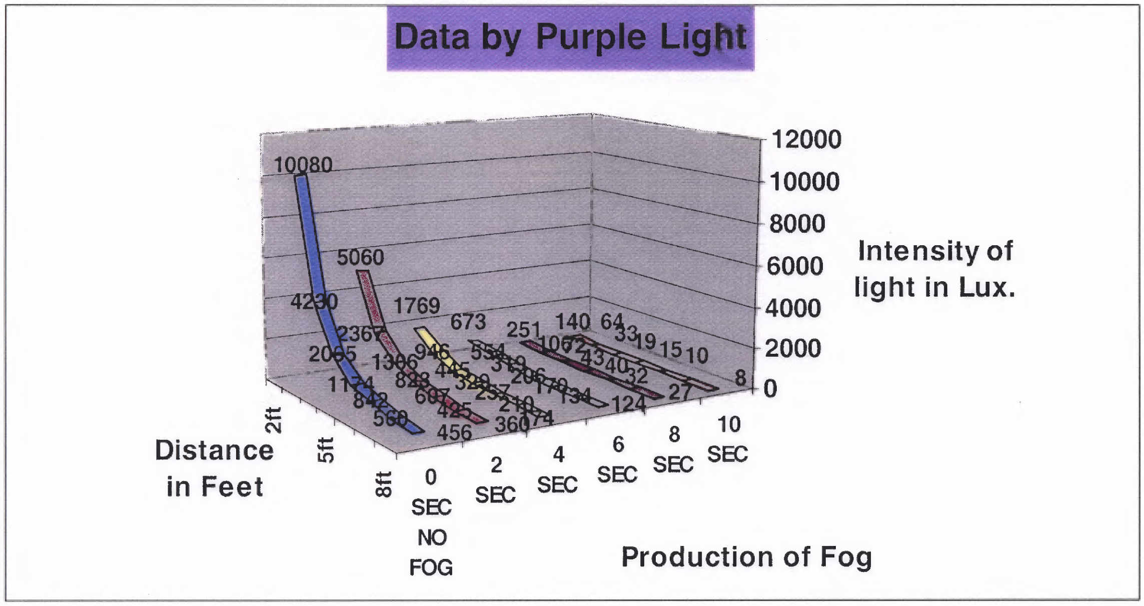


Figure 3.9 Purple light intensity at varying distance and densities of fog.

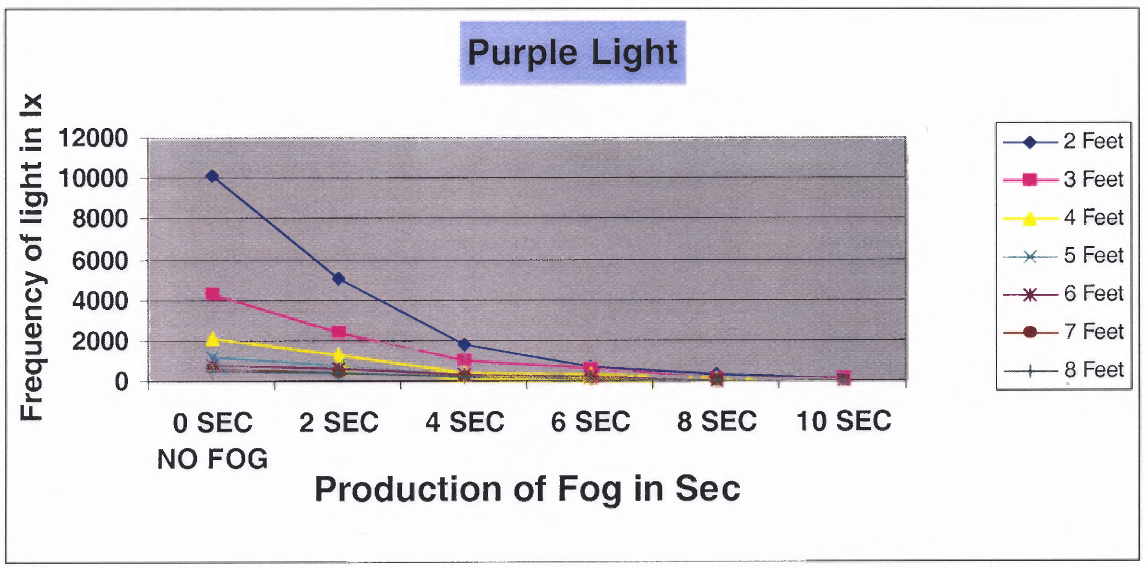


Figure 3.10 Purple light intensity versus production at varying distance.

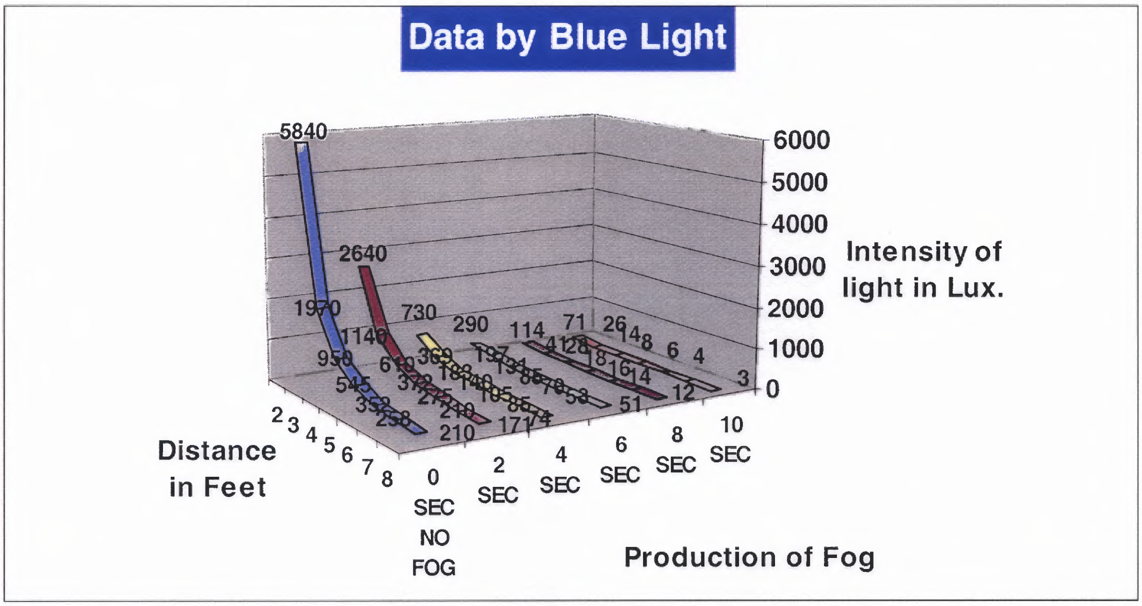


Figure 3.11 Intensity of blue light versus distance in feet and production of fog in seconds of fog production.

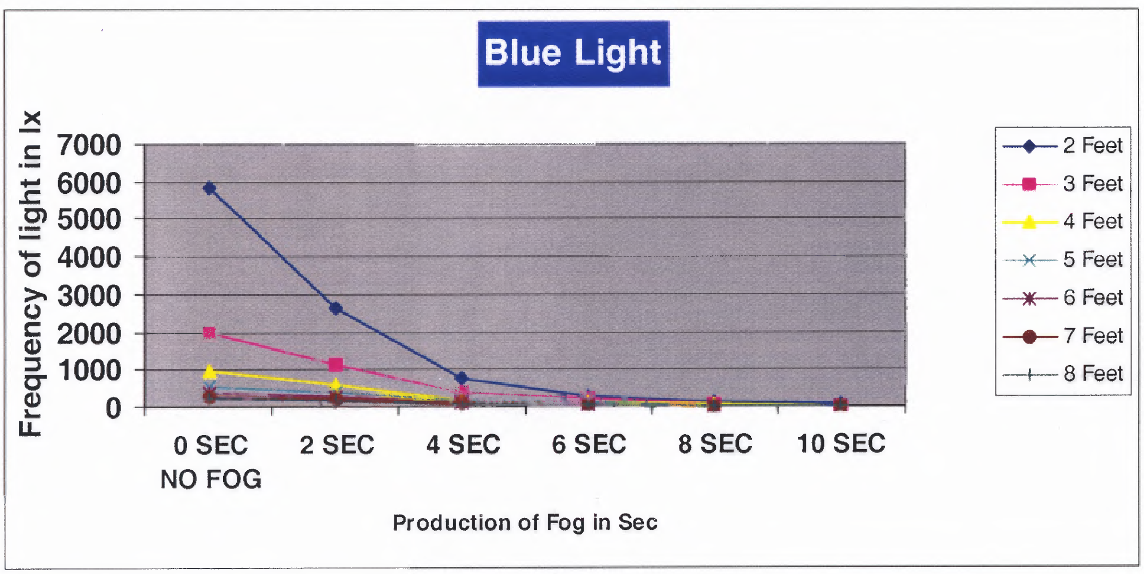


Figure 3.12 Blue light intensity at varying production of fog and distance.

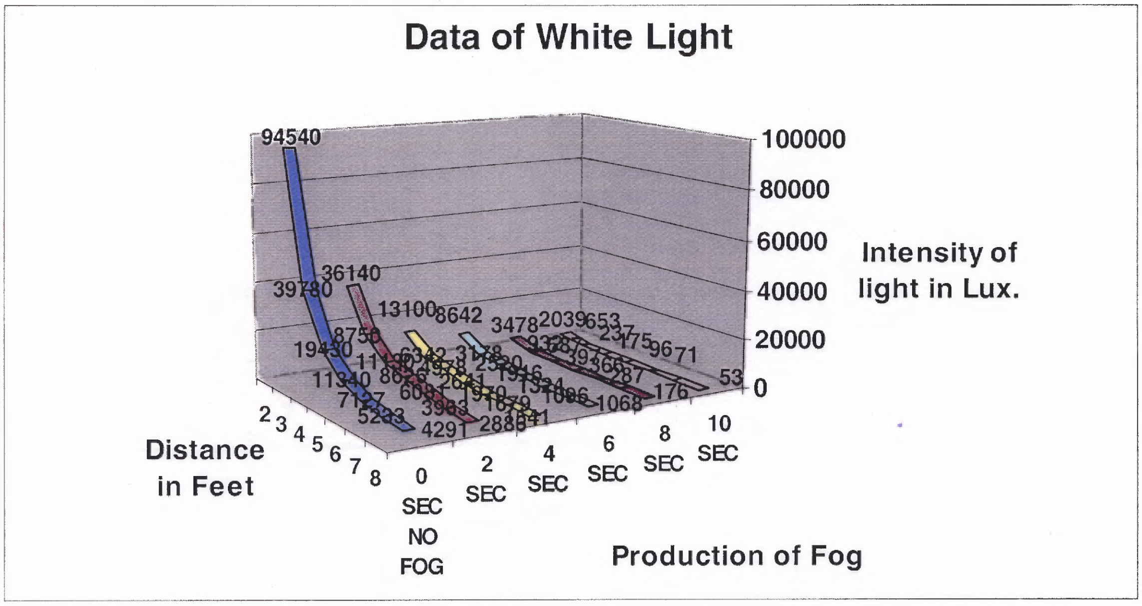


Figure 3.13 Intensity of white light measured versus distance and production.

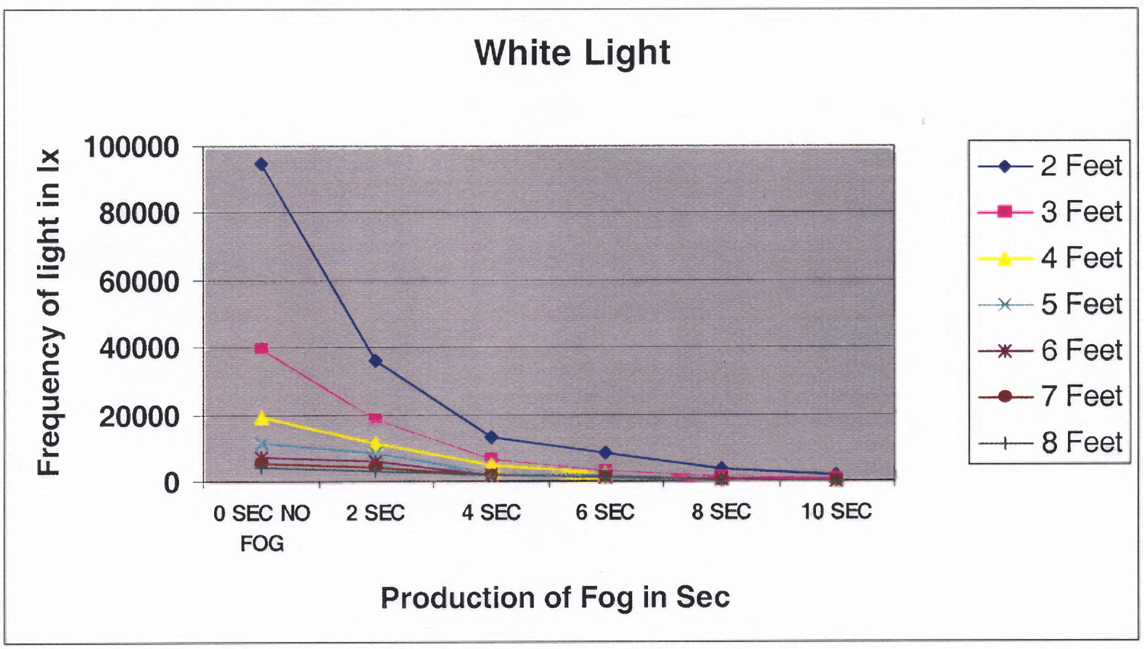


Figure 3.14 Intensity of white light is inversely proportional to production of fog and distance difference between the source and the receiver of the light.

3.1.2 Normalized Data

In the process of normalizing the light data, each color was divided by its sensitivity of the chromo meter receptor head. The percentage of each color's sensitivity are; red = 30%, orange = 65%, yellow = 99%, green = 32%, purple = 12%, blue = 6%. Therefore, the actual data of each color were divided by its sensitivity. In the data the distances are measured in feet between the transmitter and receiver, the production of fog is denoted in seconds of production of fog and intensity of different color lights are denoted in Lux.

Table 3.8 Intensity of Red Light Against Different Production and Distance

Red Light	2ft	3ft	4ft	5ft	6ft	7ft	8ft
0 SEC NO FOG	16467	7057	3407	1937	1201	887	735
2 SEC	7357	3340	2057	1337	966	728	623
4 SEC	1810	1320	643	425	320	286	245
6 SEC	1217	547	340	288	217	196	171
8 SEC	360	164	83	55	47	42	39
10 SEC	188	89	43	25	17	13	11

Table 3.9 Intensity of Orange Light Respect to Distance and Production Level of Fog

Orange Light	2ft	3ft	4ft	5ft	6ft	7ft	8ft
0 SEC NO FOG	64877	27462	13492	7902	5554	3708	3029
2 SEC	32738	16246	8360	5415	4055	2786	2426
4 SEC	12985	6075	3075	2211	1548	1306	1177
6 SEC	5095	3172	2034	1332	1055	896	808
8 SEC	1283	625	440	266	234	198	168
10 SEC	838	385	199	114	87	58	47

Table 3.10 Intensity of Yellow Light Respect to Distance and Production Level of Fog

Yellow Light	2ft	3ft	4ft	5ft	6ft	7ft	8ft
0 SEC NO FOG	90121	37960	18737	10677	6695	4959	4058
2 SEC	32273	18343	10778	6976	5122	3880	3193
4 SEC	9414	6065	3466	2351	1903	1609	1427
6 SEC	5621	3113	2164	1545	1215	1039	1018
8 SEC	1506	809	477	316	295	252	207
10 SEC	1201	522	248	141	95	73	59

Table 3.11 Intensity of Green Light Respect to Distance and Production Level of Fog

Green Light	2ft	3ft	4ft	5ft	6ft	7ft	8ft
0 SEC NO FOG	38875	16144	7691	4475	2899	2147	1738
2 SEC	15013	6866	4122	2759	2082	1583	1365
4 SEC	3666	2760	1436	946	792	694	600
6 SEC	2575	1287	828	683	530	432	414
8 SEC	828	331	202	138	125	106	88
10 SEC	490	215	106	66	46	34	29

Table 3.12 Intensity of Purple Light Respect to Distance and Production Level of Fog

Purple Light	2ft	3ft	4ft	5ft	6ft	7ft	8ft
0 SEC NO FOG	84000	35250	17208	9783	7017	4667	3800
2 SEC	42167	19725	10883	6858	5058	3542	2998
4 SEC	14742	7883	3708	2742	2144	1753	1451
6 SEC	5608	4617	2658	1713	1414	1116	1031
8 SEC	2088	887	600	362	333	267	223
10 SEC	1163	532	278	161	124	83	68

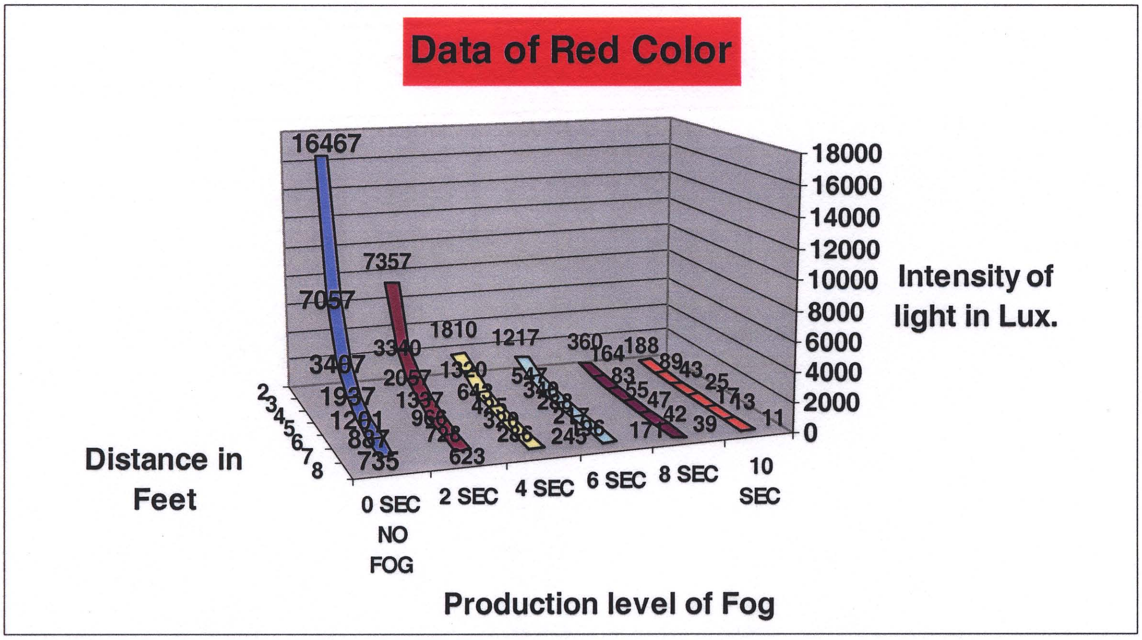


Figure 3.15 Normalized intensity of red color as a function of distance in feet and production of fog.

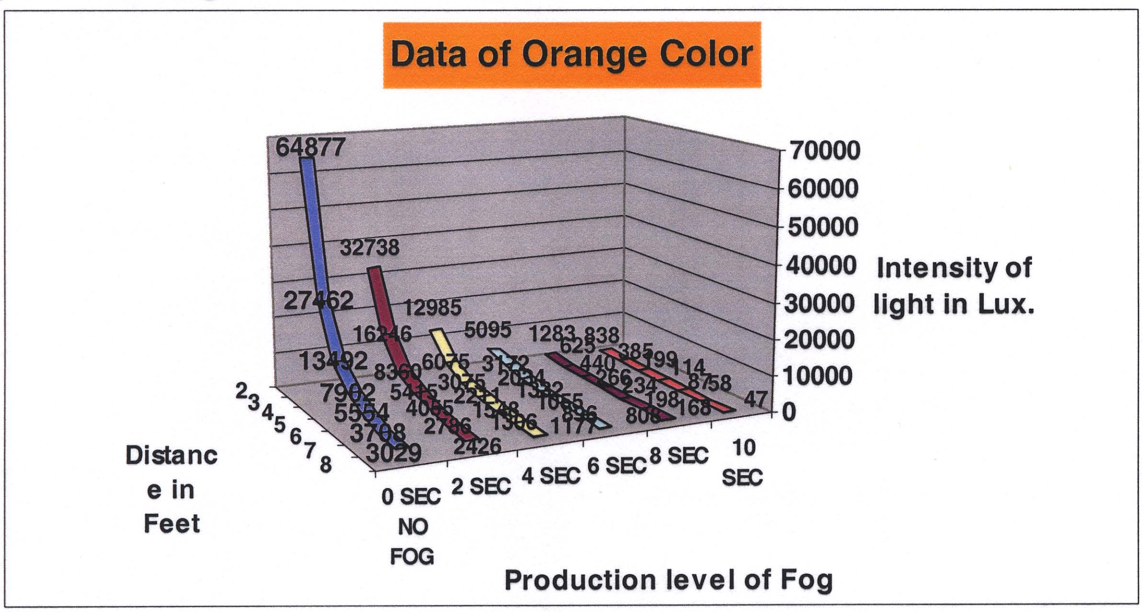


Figure 3.16 Normalized intensity of orange color as a function of distance in feet and production of fog in time of production (sec).

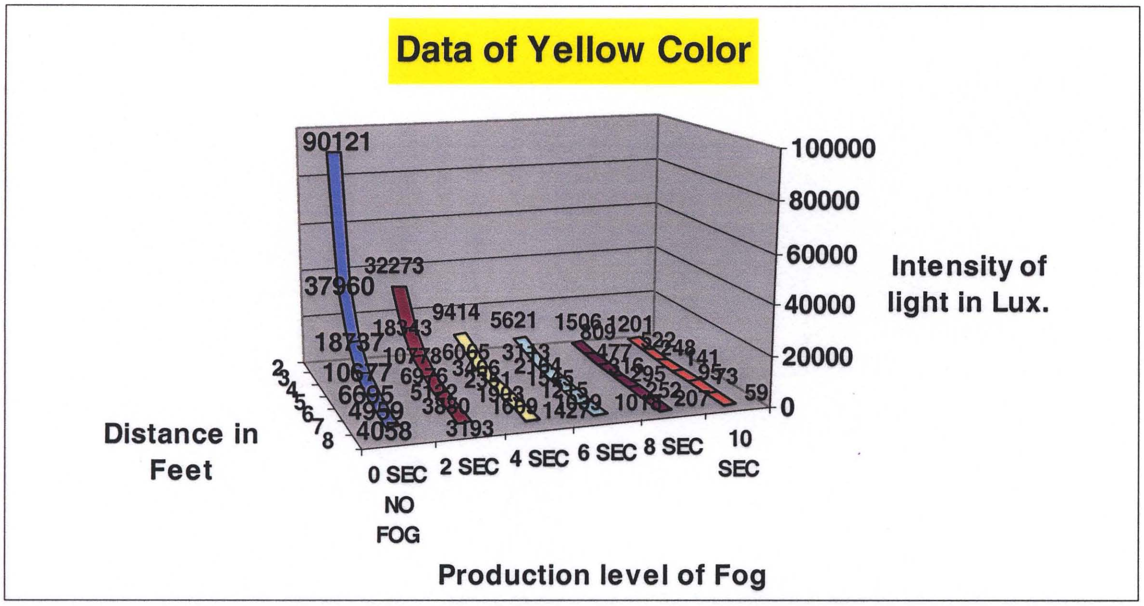


Figure 3.17 Normalized intensity of yellow color as a function of distance in feet and production of fog in time of production (sec).

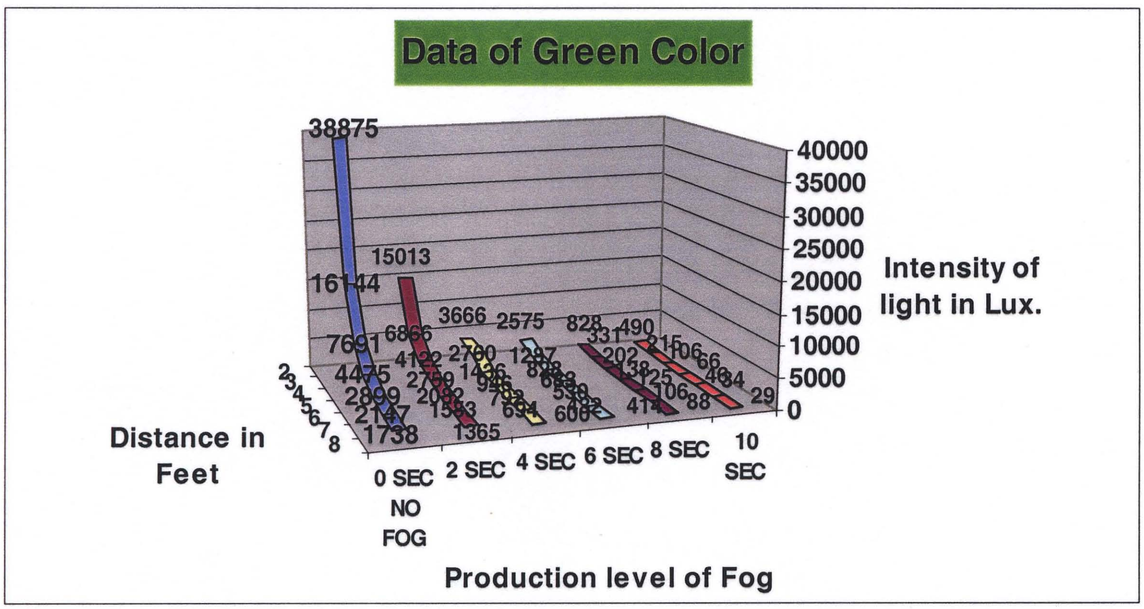


Figure 3.18 Normalized intensity of green color as a function of distance in feet and production of fog in time of production (sec).

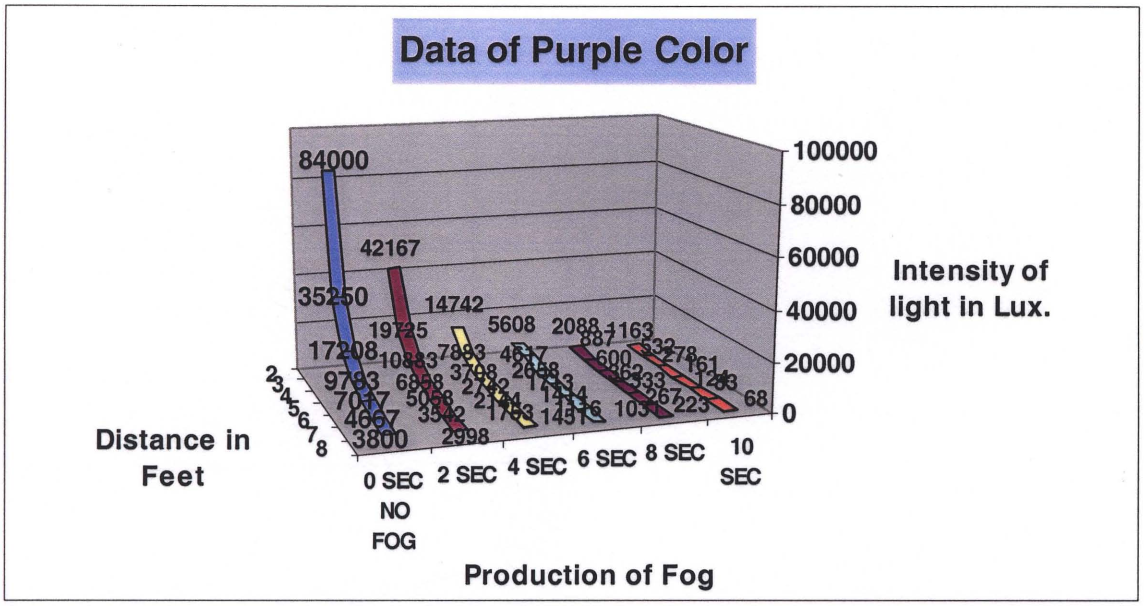


Figure 3.19 Normalized intensity of purple color as a function of distance in feet and production of fog in time of production (sec).

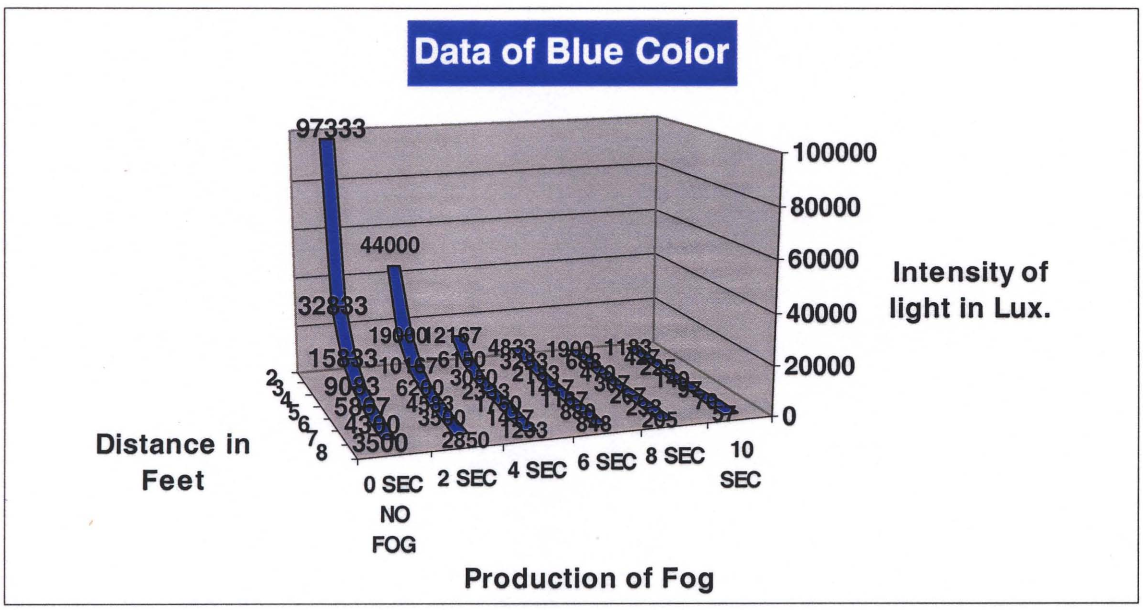


Figure 3.20 Normalized intensity of blue color as a function of distance in feet and production of fog in time of production (sec).

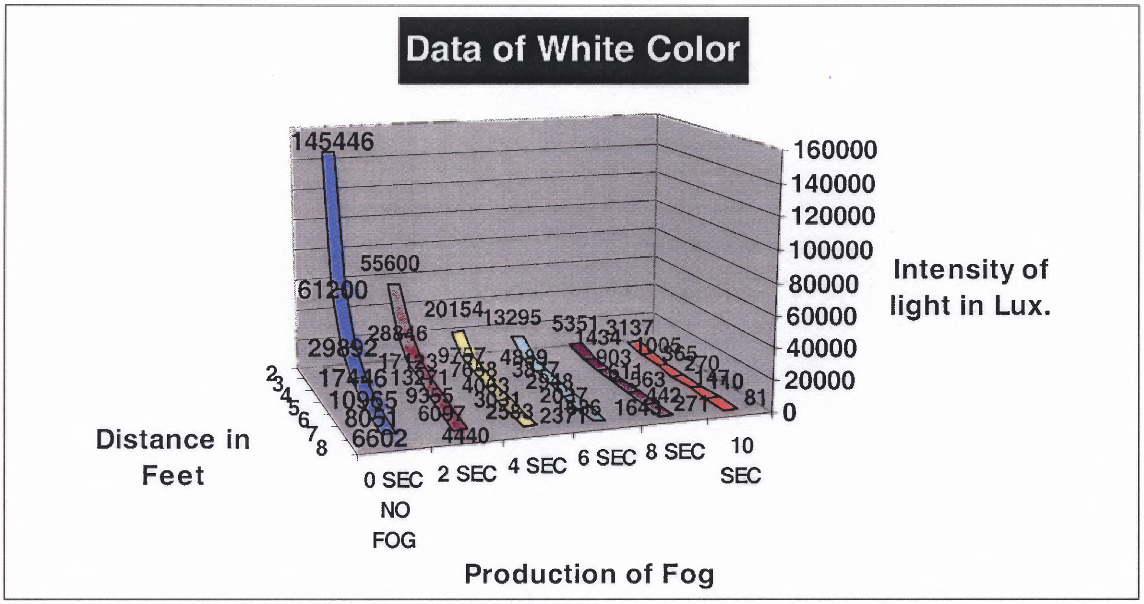


Figure 3.21 Normalized intensity of white color as a function of distance in feet and production of fog in time of production (sec).

3.1.2.1 Data Analysis as a function of Fog Production

Data were plotted based on production of the fog production from no fog (0 second) to 10 seconds of production in Figure 3.23 to 3.28.

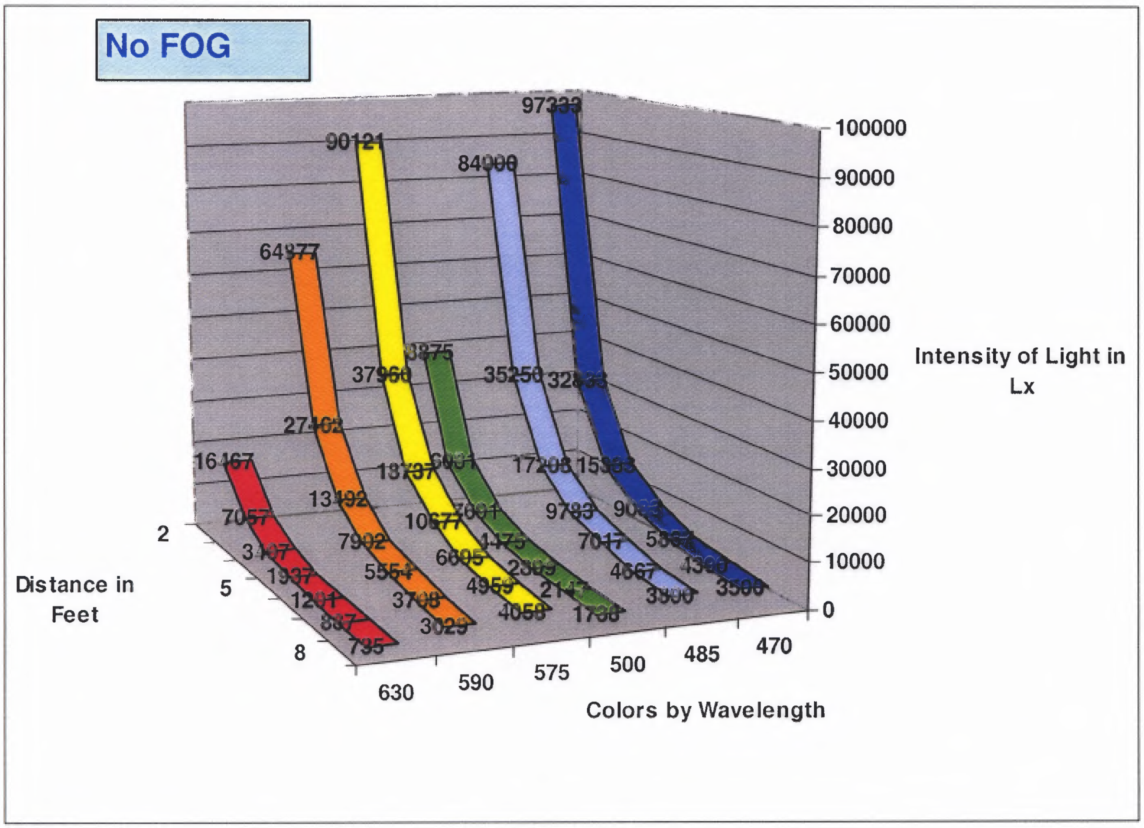


Figure 3.22 Intensity of different color lights in the ambient air (no fog) as a function of the distance between the transmitter and receiver.

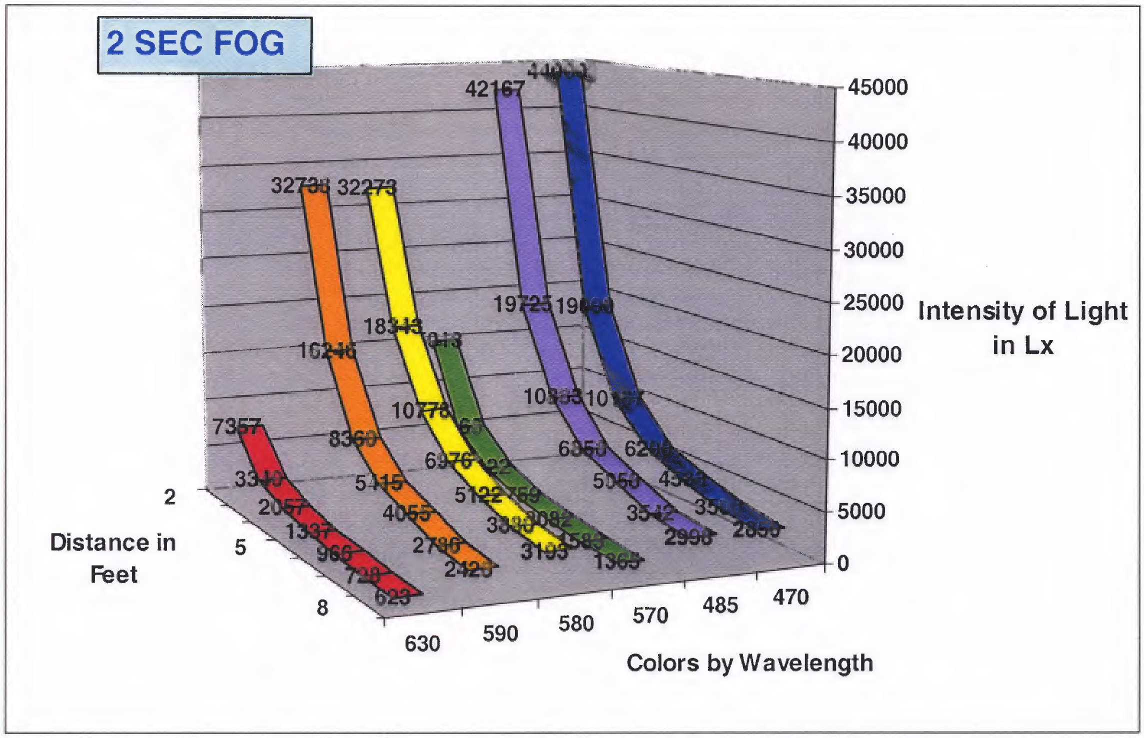


Figure 3.23 Intensity of different color lights at 2 seconds of fog production as a function of the distance between the transmitter and receiver.

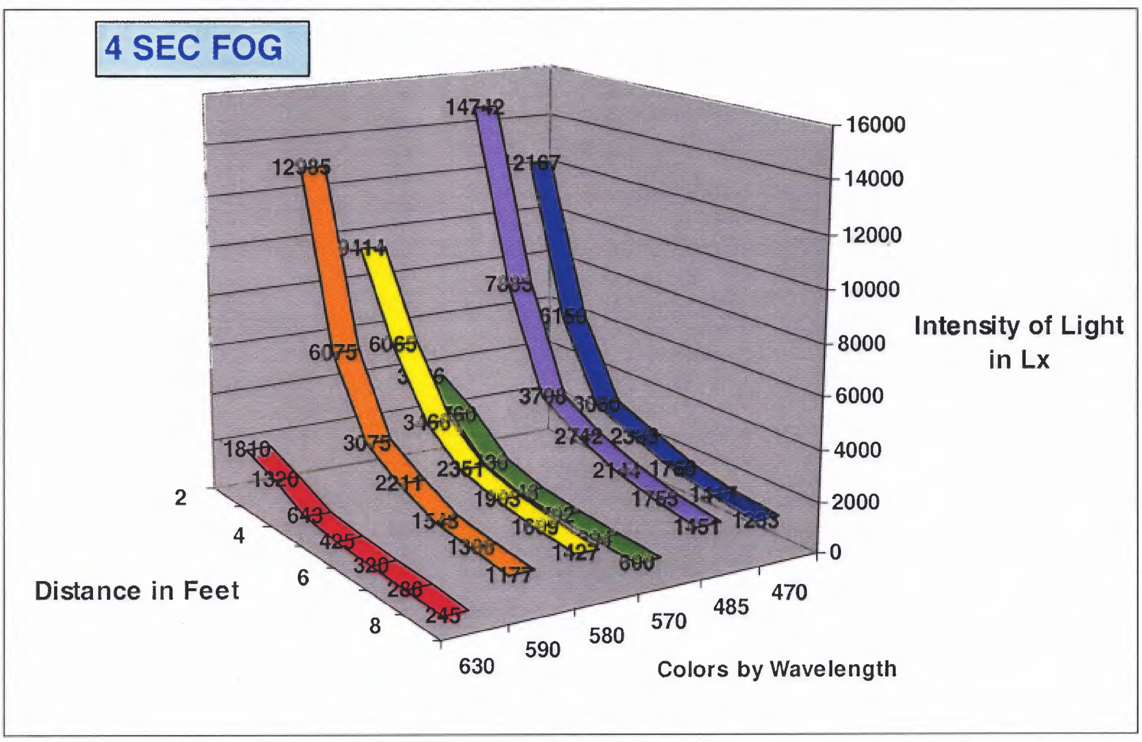


Figure 3.24 Intensity of different colors lights with 4 seconds of fog production as a function of the distance between the transmitter and receiver.

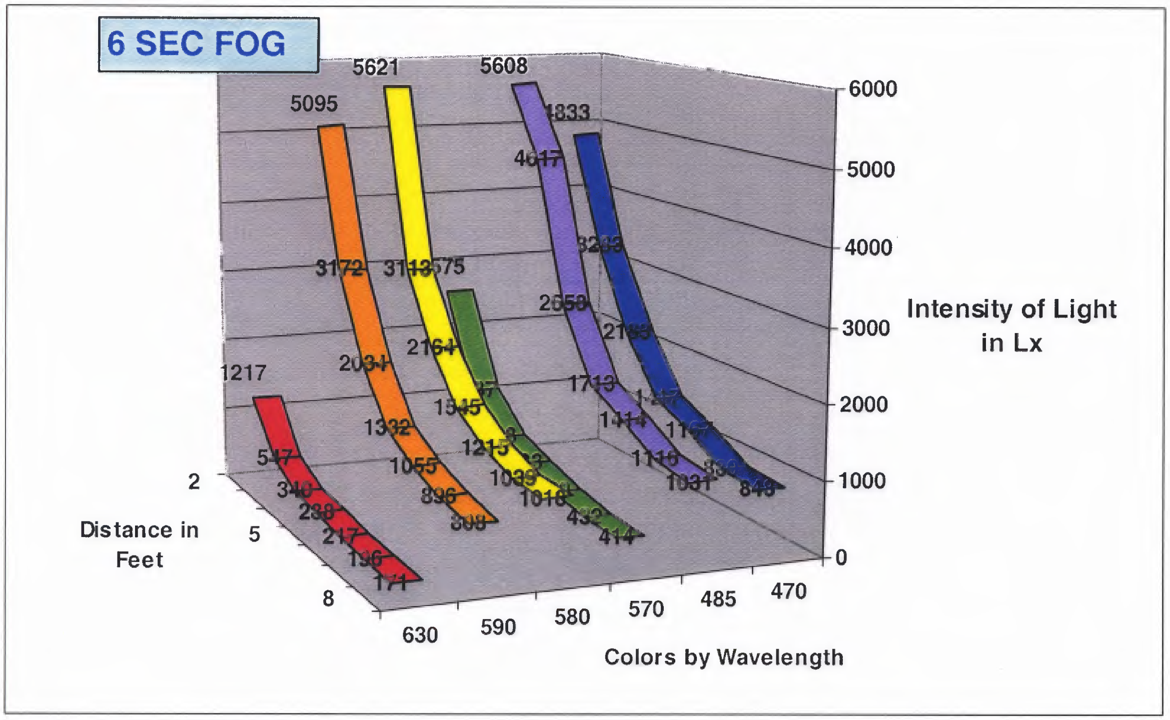


Figure 3.25 Intensity of different colors lights with 6 seconds of fog production as a function of the distance between the transmitter and receiver.

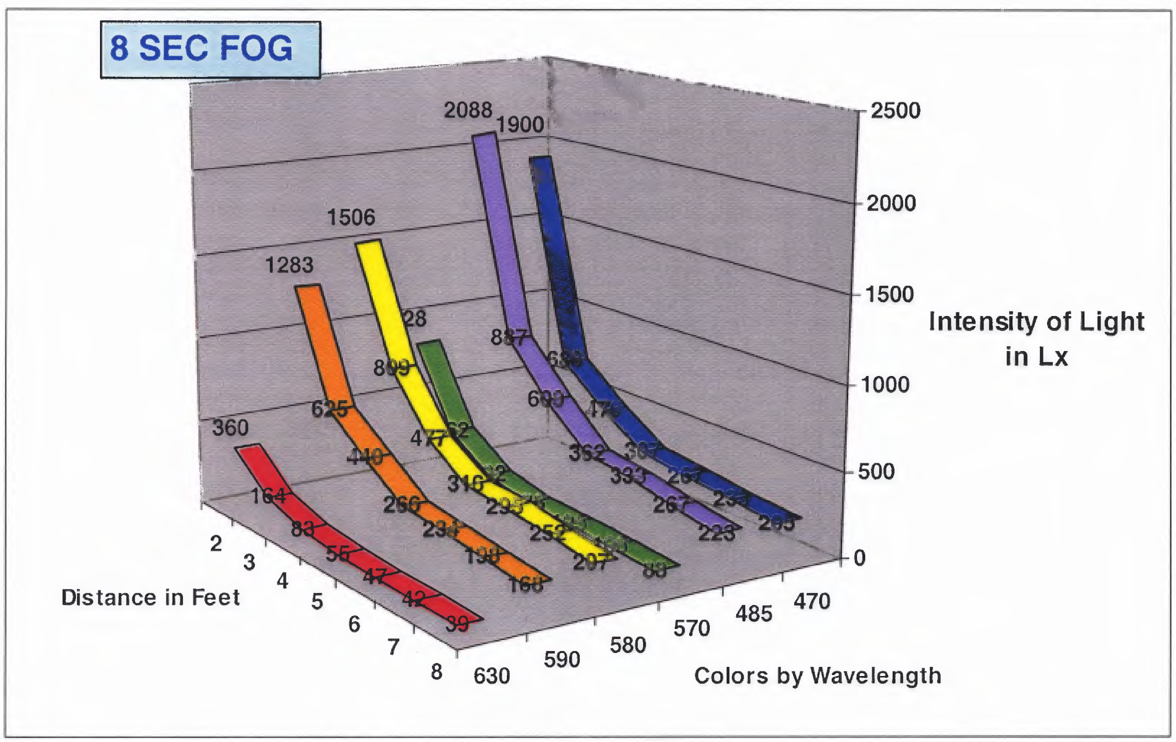


Figure 3.26 Intensity of different colors lights with 8 seconds of fog production as a function of the distance between the transmitter and receiver.

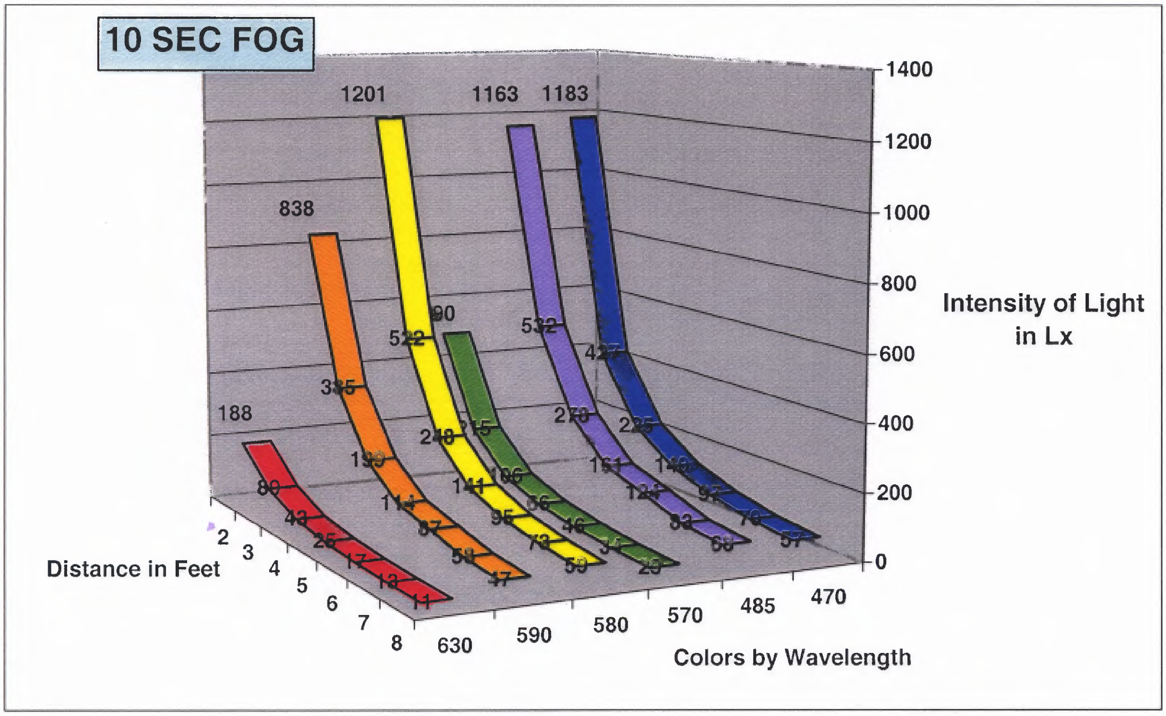


Figure 3.27 Intensity of different colors lights with 10 seconds of fog production as a function of the distance between the transmitter and receiver.

Each graph was also plotted by calculating the percentage difference between the data with no fog and data with fog. Each production level of fog data was compared with the data obtained in the ambient air experiment (no fog) and the percentage difference was calculated using the formula as shown below.

$$\% = \frac{\text{Data measured from no fog} - \text{Data measured with fog}}{\text{Data measured from no fog}} \times 100 \quad (3.1)$$

Each of the graphs shown below plots percentage lost from 0second(no fog) to 2, 4, 6, 8, and 10 seconds of fog production. Each color has been represented in the graphs by its actual wavelength; red(630), orange(590), yellow(575), green(500), purple(485), blue(470). All the graphs are grouped by each production of the fog production; 0 (no fog), 2, 4, 6, 8, and 10 seconds. The percentage lost from the control of no fog to each of the various fog conditions facilitates interpretation of the data. Using the formula (3.1) percentage difference between no fog to 2seconds, 4 seconds, 6 seconds, 8 seconds, and

10 seconds were calculated. This analysis exploited differences found in the data by comparing the control (no fog) to each of the different tests (fog production of 2 through 10 seconds).

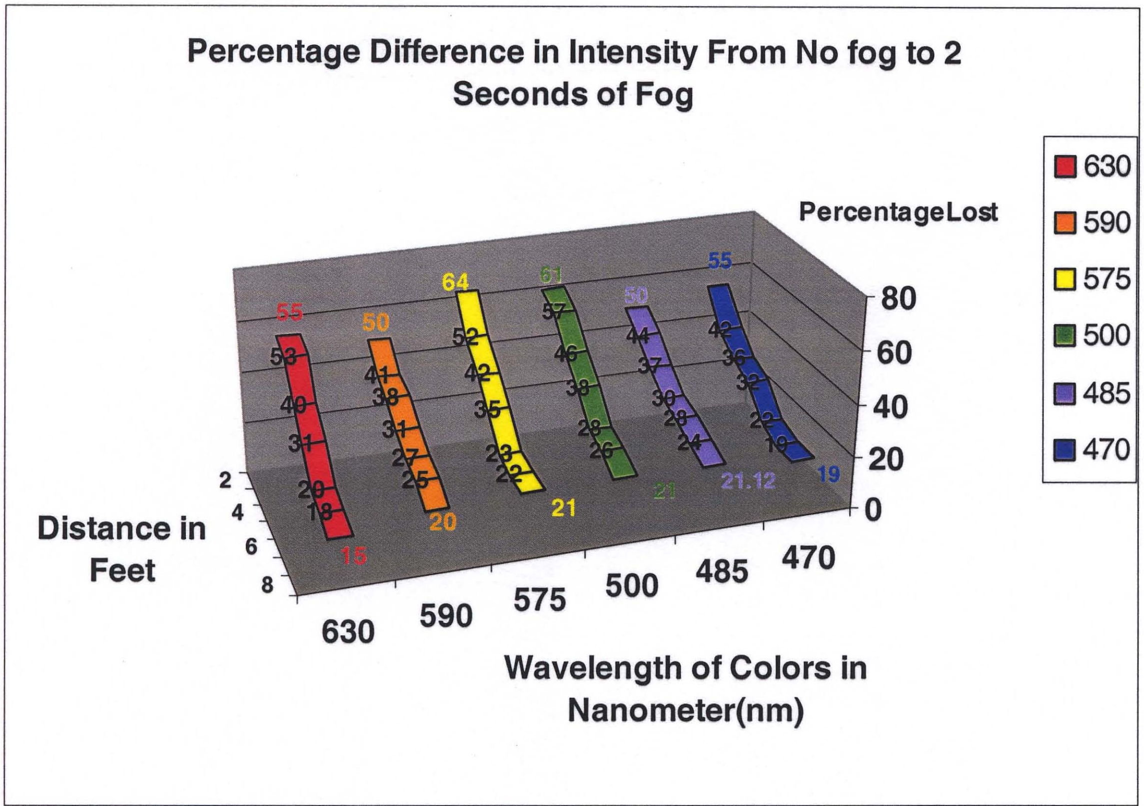


Figure 3.28 Percentage difference or percentage lost in intensity, of six different colors of light, from control to 2 seconds of fog production as a function of distance between the transmitter and receiver.

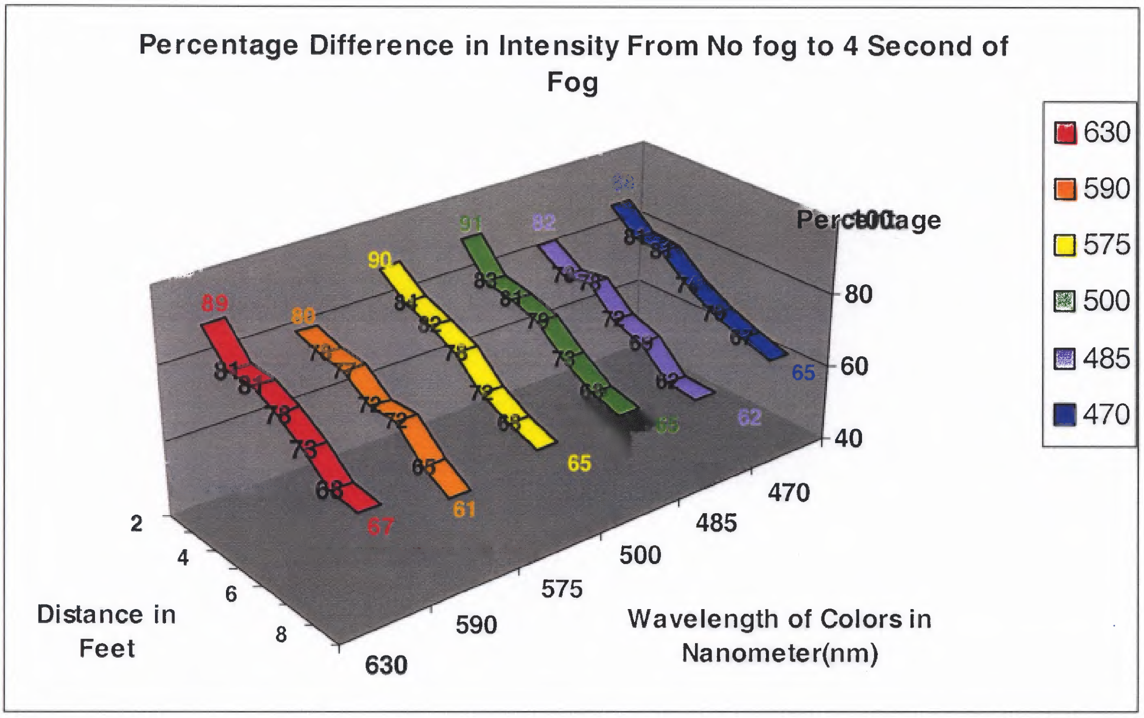


Figure 3.29 Percentage difference or percentage lost in intensity, of six different colors of light, from control to 4 seconds of fog production as a function of distance between the transmitter and receiver.

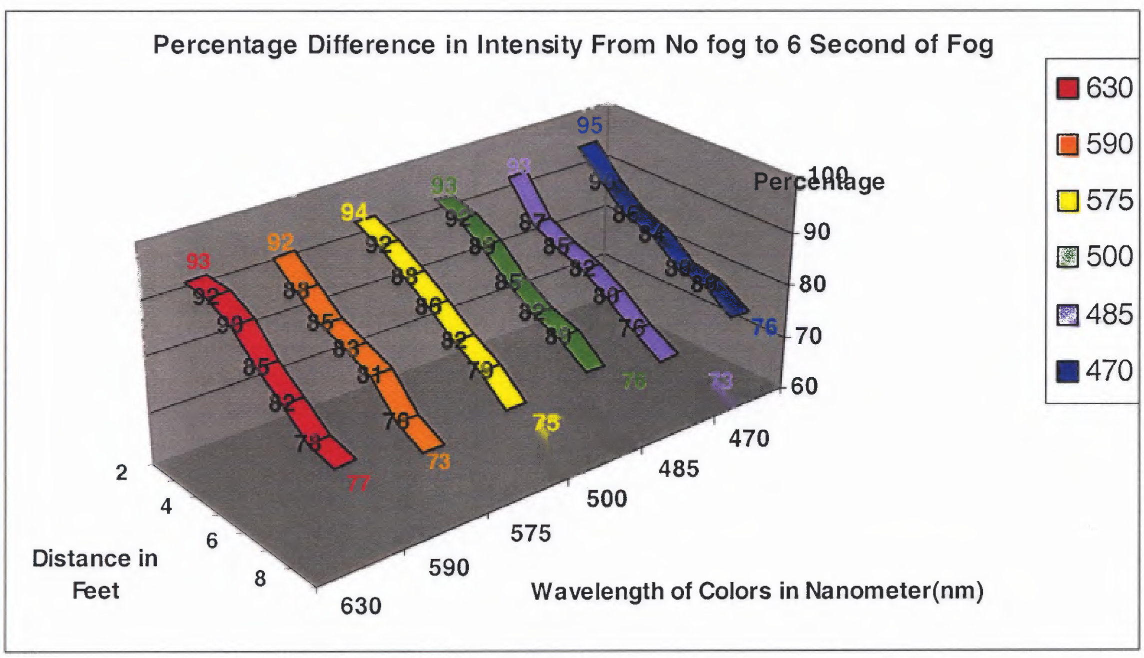


Figure 3.30 Percentage difference or percentage lost in intensity, of six different colors of light, from control to 6 seconds of fog production as a function of distance between the transmitter and receiver.

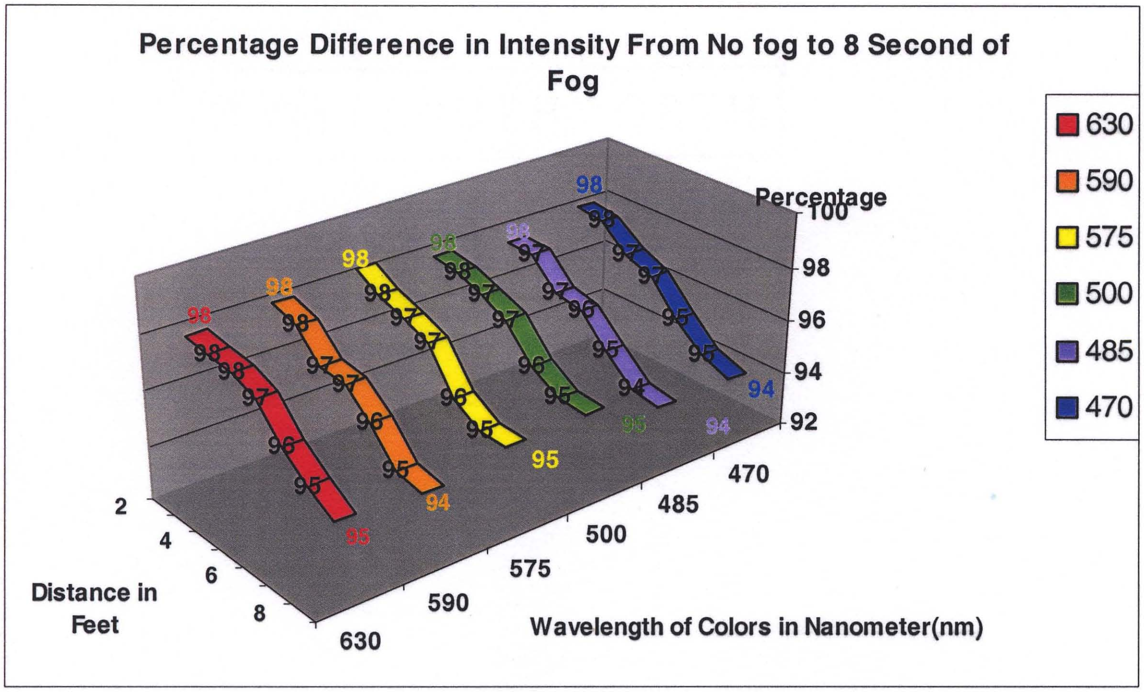


Figure 3.31 Percentage difference or percentage lost in intensity, of six different colors of light, from control to 8 seconds of fog production as a function of distance between the transmitter and receiver.

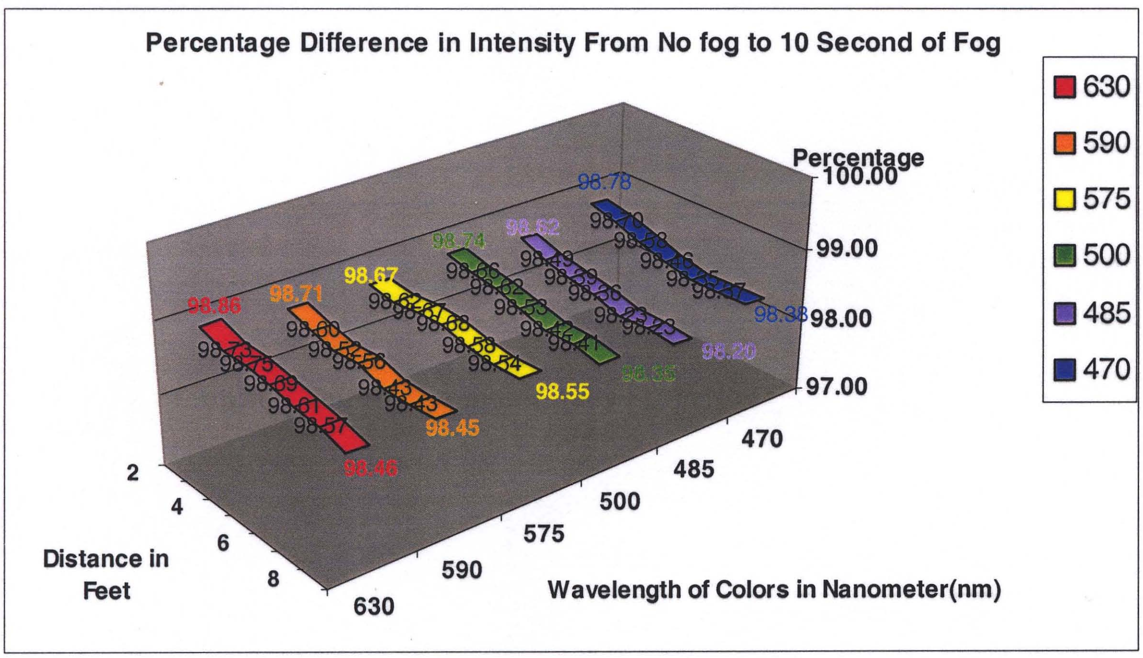


Figure 3.32 Percentage difference or percentage lost in intensity, of six different colors of light, from control to 10 seconds of fog production as a function of distance between the transmitter and receiver.

3.1.2.2 Data by Distance

Light normalized data were then grouped by distance and graphed as a function of fog production in seconds and percentage difference from no fog to different production of fog starting from 2, 4, 6, 8, and 10 seconds.

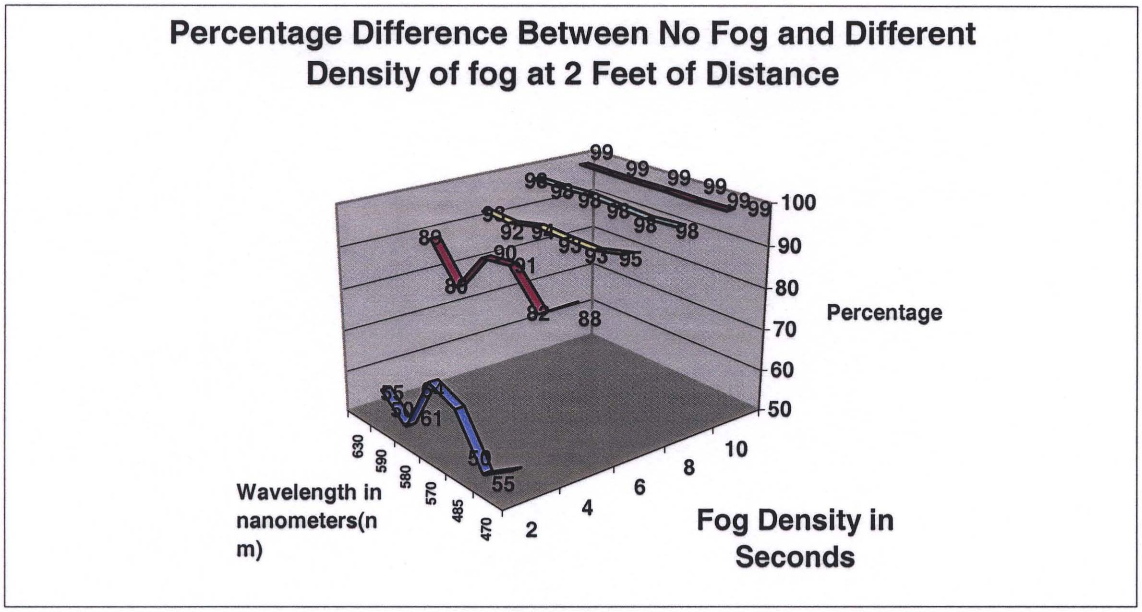


Figure 3.33 Light intensity percent difference when the difference between the transmitter and receiver was 2 feet for varying fog production times denoted in seconds.

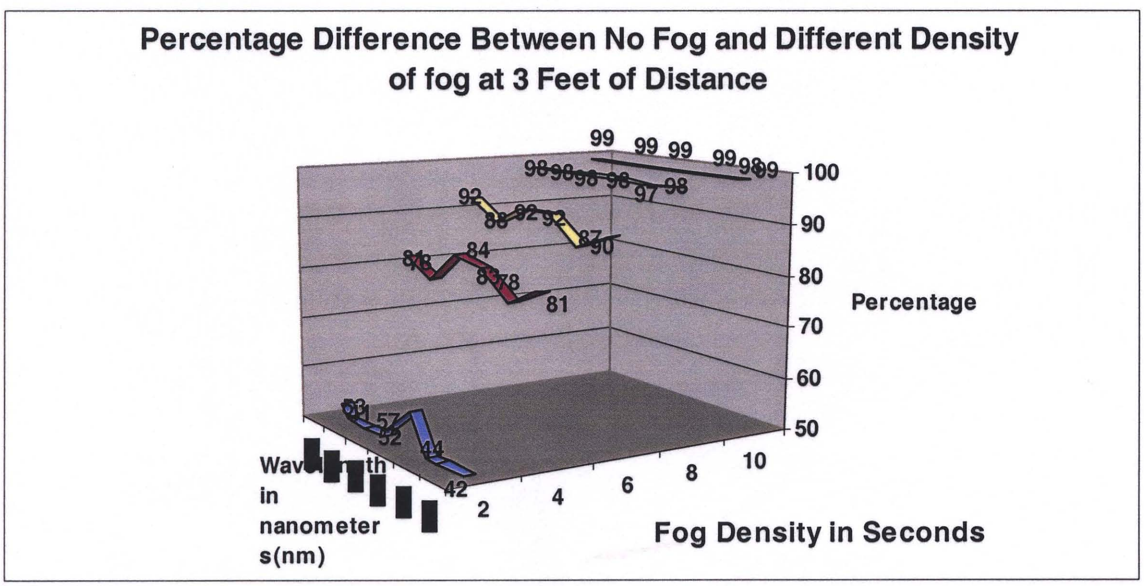


Figure 3.34 Light intensity percent difference when the difference between the transmitter and receiver was 3 feet for varying fog production times denoted in seconds.

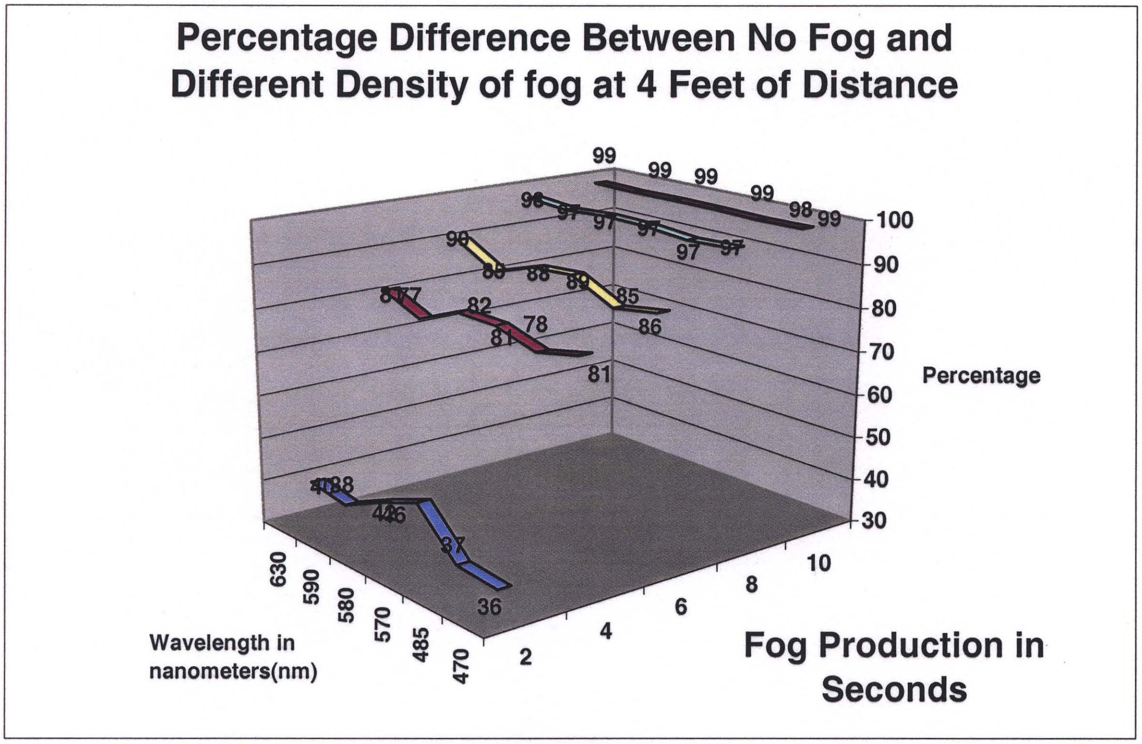


Figure 3.35 Light intensity percent difference when the difference between the transmitter and receiver was 4 feet for varying fog production times denoted in seconds.

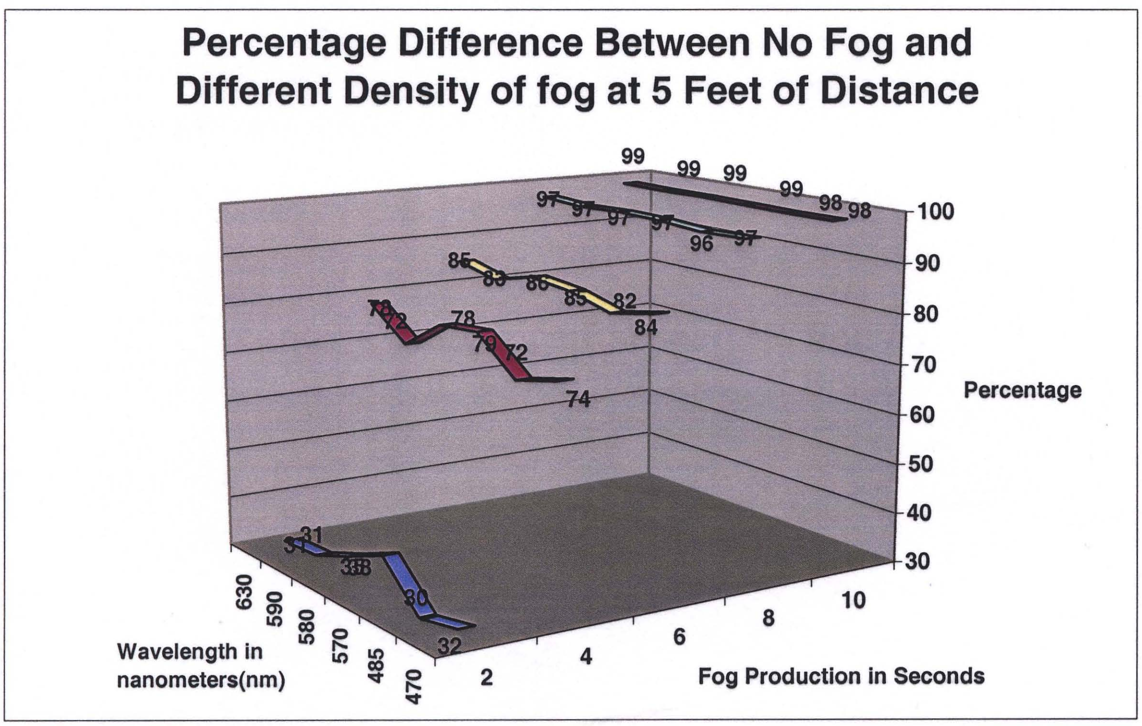


Figure 3.36 Light intensity percent difference when the difference between the transmitter and receiver was 5 feet for varying fog production times denoted in seconds.

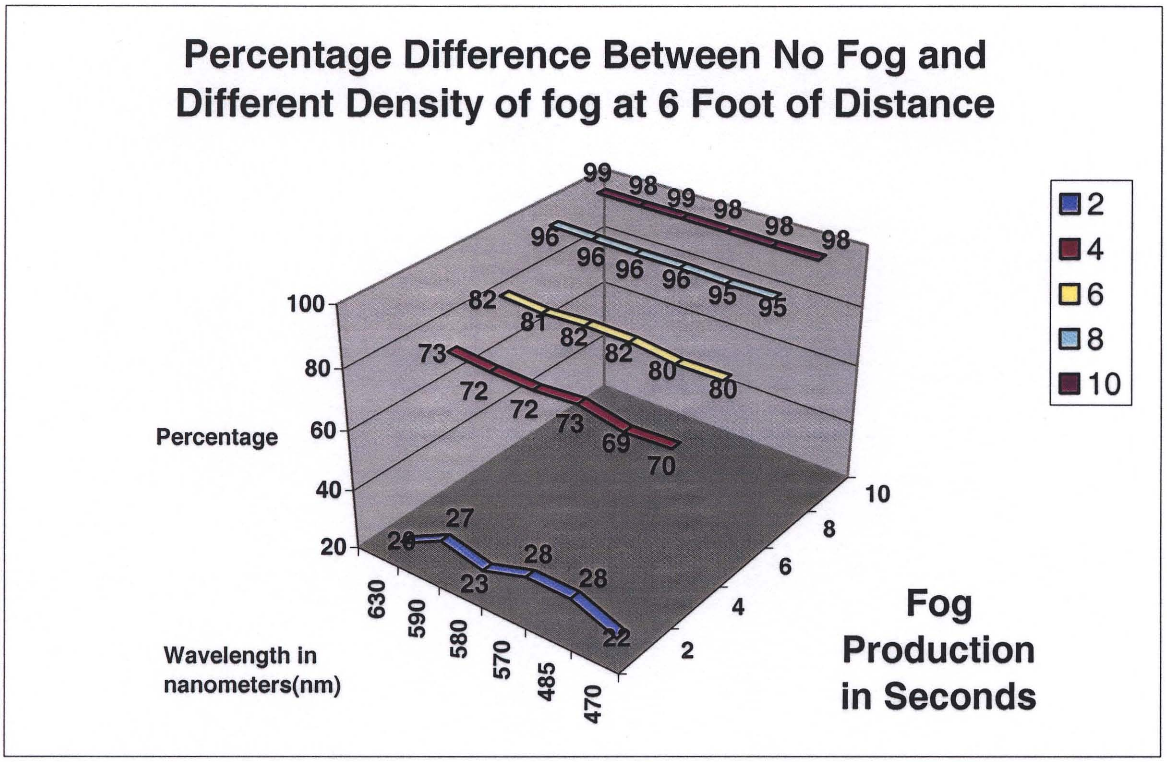


Figure 3.37 Light intensity percent difference when the difference between the transmitter and receiver was 6 feet for varying fog production times denoted in seconds.

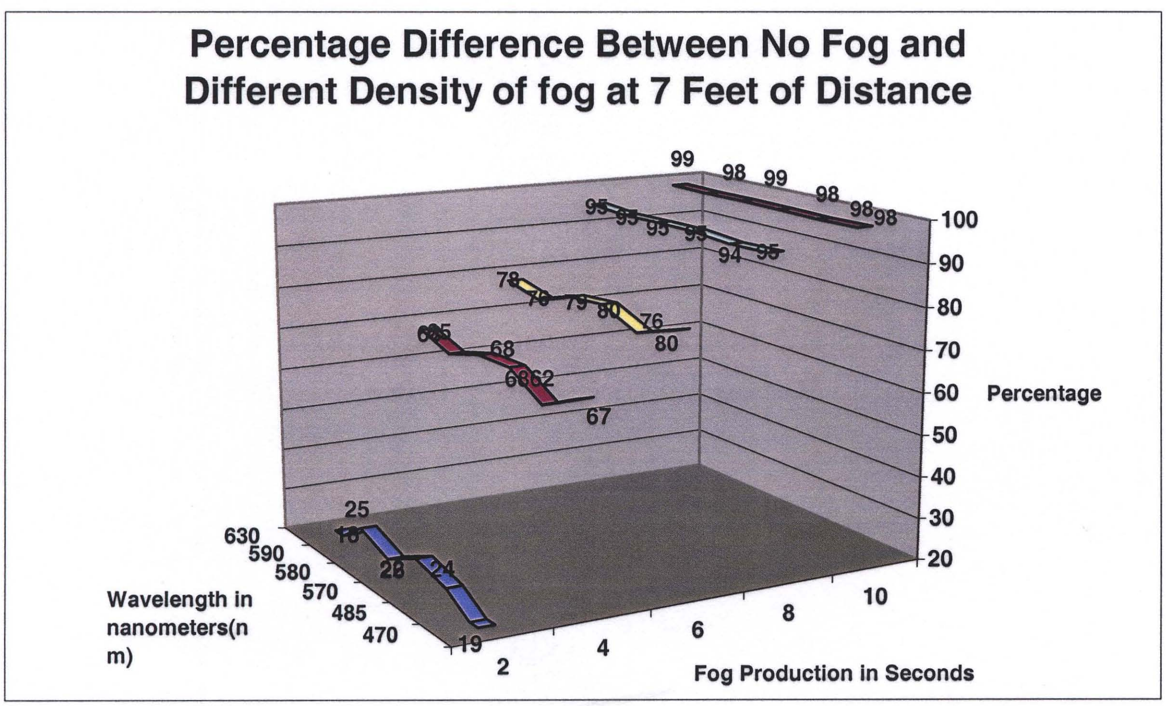


Figure 3.38 Light intensity percent difference when the difference between the transmitter and receiver was 7 feet for varying fog production times denoted in seconds.

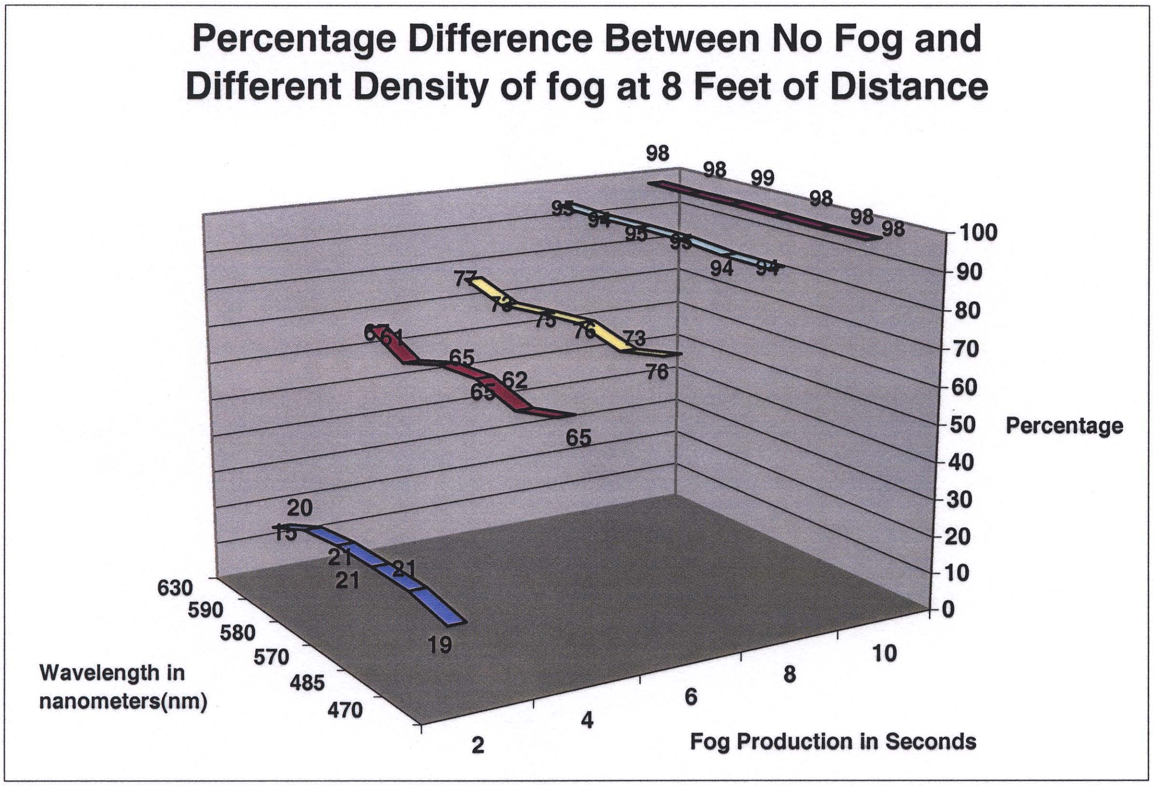


Figure 3.39 Light intensity percent difference when the difference between the transmitter and receiver was 8 feet for varying fog production times denoted in seconds.

3.2 Sound Results

The results of the sound experiment quantified thirty-eight sound frequencies, starting from 50 Hz to 20,000 Hz, for different distance measurements between the speaker and microphone starting from 1 foot to 8 feet, in one-foot increments. The results also have varying fog production times of; 10, 20, 30, 40 seconds of fog as well as the control which was a no fog environment or 0 seconds of fog production. In chapter 3.2.1, tables are shown which are grouped by fog production time and in chapter 3.2.2 graphs are shown for the tables in section 3.2.1. How each frequency of the sound reacts under varying distance (in feet) and the production of the fog (in seconds) is easier to visualize through graphs.

3.2.1 Tables of Sound Experiment

Data were saved into the excel spreadsheets automatically by the custom Lab-VIEW program developed for this research. The recorded frequency of sound was converted to decibels by using the formula (2.1) shown in section 1.3.1. The three parameter used in the data collection of the sound experiments are; frequency in hertz, distance in feet and the fog production in seconds.

First of all, sound was recorded under no fog condition (table 3.13). There were thirty eight different sound files starting from 50Hz to 20 KHz used in this experiment. Data were collected using 8 different distances; one foot to eight feet of distances.

Table 3.13 Sound Recorded During Control (no Fog) as a Function of Distance Between the Transmitter and Receiver for Frequencies Between 50 to 20, 000 Hz and Intensity of Sound are Denoted in Decibel

0 SEC NO FOG	1FT	2FT	3FT	4FT	5FT	6FT	7FT	8FT
50Hz	72.775 dB	71.869 dB	71.107 dB	71.334 dB	71.126 dB	71.548 dB	71.515 dB	71.062 dB
100 Hz	85.844 dB	79.839 dB	76.426 dB	75.847 dB	75.374 dB	73.926 dB	74.326 dB	76.253 dB
150 Hz	92.853 dB	87.148 dB	81.482 dB	75.213 dB	72.69 dB	73.71 dB	75.866 dB	80.329 dB
200 Hz	87.389 dB	77.272 dB	82.7 dB	84.499 dB	82.653 dB	78.004 dB	74.643 dB	75.345 dB
250 Hz	82.733 dB	75.108 dB	78.837 dB	81.231 dB	78.596 dB	70.15 dB	76.583 dB	74.39 dB
300 Hz	86.377 dB	84.873 dB	80.654 dB	78.619 dB	78.961 dB	76.501 dB	71.626 dB	73.946 dB
350 Hz	84.515 dB	77.73 dB	79.021 dB	77.632 dB	72.186 dB	77.197 dB	76.03 dB	75.385 dB
400 Hz	85.562 dB	82.914 dB	78.748 dB	73.497 dB	81.78 dB	76.553 dB	79.564 dB	76.618 dB
450 Hz	86.52 dB	83.938 dB	72.588 dB	75.487 dB	83.153 dB	73.366 dB	77.758 dB	74.736 dB
500 Hz	84.532 dB	83.627 dB	85.2 dB	72.133 dB	75.711 dB	74.83 dB	76.439 dB	78.277 dB
550 Hz	83.852 dB	75.809 dB	76.199 dB	77.866 dB	75.152 dB	74.54 dB	73.288 dB	74.033 dB
600 Hz	79.678 dB	76.912 dB	73.256 dB	77.169 dB	72.375 dB	75.641 dB	75.06 dB	75.914 dB
650 Hz	81.203 dB	73.677 dB	71.833 dB	74.589 dB	71.47 dB	72.818 dB	71.142 dB	75.495 dB
700 Hz	81.47 dB	82.282 dB	78.628 dB	71.89 dB	78.536 dB	76.863 dB	72.931 dB	76.02 dB
750 Hz	84.174 dB	81.91 dB	76.209 dB	74.082 dB	78.021 dB	74.911 dB	76.983 dB	77.922 dB
800 Hz	82.544 dB	75.922 dB	75.577 dB	72.658 dB	74.66 dB	74.998 dB	77.934 dB	73.307 dB
850 Hz	84.743 dB	83.066 dB	73.749 dB	75.64 dB	71.855 dB	76.805 dB	80.06 dB	78.166 dB
900 Hz	84.586 dB	77.61 dB	77.952 dB	73.731 dB	74.905 dB	72.592 dB	76.366 dB	78.995 dB
1000 Hz	82.699 dB	77.88 dB	75.459 dB	76.821 dB	73.621 dB	76.356 dB	74.495 dB	77.894 dB
2000 Hz	82.683 dB	79.1 dB	77.437 dB	78.377 dB	76.276 dB	75.502 dB	75.085 dB	75.058 dB
3000 Hz	86.782 dB	81.421 dB	72.904 dB	79.024 dB	75.499 dB	79.307 dB	71.616 dB	72.302 dB
4000 Hz	80.221 dB	75.421 dB	73.826 dB	72.563 dB	74.588 dB	72.627 dB	70.871 dB	74.847 dB
5000 Hz	86.435 dB	84.523 dB	80.949 dB	77.287 dB	77.159 dB	74.342 dB	74.422 dB	75.664 dB
6000 Hz	87.664 dB	86.165 dB	83.454 dB	80.982 dB	79.102 dB	79.993 dB	74.404 dB	74.812 dB
7000 Hz	85.456 dB	83.856 dB	80.979 dB	78.324 dB	76.781 dB	78.574 dB	78.654 dB	76.556 dB
8000 Hz	91.146 dB	88.134 dB	86.337 dB	84.806 dB	82.646 dB	80.903 dB	78.867 dB	75.611 dB
9000 Hz	91.212 dB	87.052 dB	82.375 dB	79.344 dB	78.783 dB	78.449 dB	73.303 dB	73.326 dB
10000 Hz	87.671 dB	85.26 dB	83.689 dB	80.573 dB	79.813 dB	77.511 dB	77.098 dB	76.17 dB
11000 Hz	73.721 dB	79.555 dB	77.617 dB	77.284 dB	74.913 dB	74.358 dB	73.006 dB	74.088 dB
12000 Hz	74.121 dB	76.659 dB	74.582 dB	73.809 dB	72.834 dB	71.627 dB	71.036 dB	71.326 dB
13000 Hz	77.949 dB	79.748 dB	75.75 dB	73.761 dB	72.151 dB	72.279 dB	71.062 dB	71.146 dB
14000 Hz	82.591 dB	81.75 dB	78.613 dB	75.475 dB	74.263 dB	73.102 dB	72.505 dB	72.267 dB
15000 Hz	82.164 dB	82.259 dB	79.206 dB	76.453 dB	74.594 dB	74.66 dB	73.768 dB	73.399 dB
16000 Hz	84.177 dB	84.097 dB	80.576 dB	77.762 dB	76.513 dB	74.597 dB	72.912 dB	73.658 dB
17000 Hz	88.455 dB	83.12 dB	81.6 dB	79.64 dB	76.357 dB	75.72 dB	74.044 dB	75.531 dB
18000 Hz	86.53 dB	83.236 dB	80.22 dB	77.612 dB	76.213 dB	74.386 dB	74.06 dB	73.371 dB
19000 Hz	87.559 dB	83.979 dB	82.463 dB	79.895 dB	76.381 dB	75.552 dB	73.925 dB	73.145 dB
20000 Hz	85.479 dB	83.138 dB	80.863 dB	78.909 dB	75.788 dB	75.223 dB	74.598 dB	73.189 dB

Then data were collected under 10 seconds of fog with the same parameters used under no fog experiment. Table 3.14 shows the data collected under 10 seconds of fog production.

Table 3.14 Sound Recorded During 10 Seconds of Fog Production as a Function of Distance Between the Transmitter and Receiver for Frequencies Between 50 to 20, 000 Hz and Intensity of Sound are Denoted in Decibel

10 SEC OF FOG	1ft	2ft	3ft	4ft	5ft	6ft	7ft	8ft
50Hz	72.515dB	72.299dB	72.603dB	71.881dB	71.884dB	72.268dB	72.169dB	72.142dB
100Hz	83.781dB	79.389dB	78.48dB	78.19dB	77.894dB	76.795dB	74.839dB	74.687dB
150Hz	91.317dB	88.138dB	83.305dB	77.63dB	72.972dB	72.939dB	73.497dB	73.013dB
200Hz	87.373dB	74.623dB	80.715dB	84.372dB	83.4dB	79.267dB	75.426dB	75.169dB
250Hz	83.35dB	75.189dB	78.153dB	80.043dB	78.592dB	72.279dB	77.003dB	76.651dB
300Hz	81.667dB	81.305dB	77.868dB	75.035dB	79.082dB	77.603dB	74.909dB	73.345dB
350Hz	84.166dB	76.202dB	78.051dB	80.263dB	77.02dB	75.916dB	72.7dB	72.352dB
400Hz	85.716dB	81.797dB	77.071dB	75.971dB	79.094dB	77.633dB	75.88dB	73.496dB
450Hz	82.945dB	81.954dB	74.109dB	77.321dB	76.882dB	72.667dB	72.363dB	71.398dB
500Hz	82.736dB	79.71dB	82.265dB	76.07dB	74.948dB	80.507dB	74.126dB	72.644dB
550Hz	82.471dB	80.976dB	76.206dB	75.288dB	73.477dB	72.413dB	74.164dB	75.159dB
600Hz	78.719dB	78.875dB	73.089dB	74.383dB	76.453dB	72.581dB	76.976dB	72.337dB
650Hz	81.867dB	74.903dB	75.599dB	72.475dB	77.521dB	76.099dB	74.655dB	73.233dB
700Hz	78.804dB	78.681dB	74.703dB	73.041dB	75.362dB	74.837dB	76.002dB	78.122dB
750Hz	81.196dB	75.812dB	74.672dB	74.218dB	73.334dB	74.233dB	75.551dB	76.899dB
800Hz	79.577dB	74.469dB	72.816dB	74.872dB	74.498dB	74.293dB	73.76dB	76.219dB
850Hz	82.074dB	81.717dB	77.919dB	74.54dB	74.076dB	73.326dB	73.697dB	75.143dB
900Hz	81.702dB	77.557dB	75.071dB	80.601dB	73.438dB	72.935dB	75.891dB	77.755dB
1000Hz	81.71dB	77.347dB	82.143dB	75.407dB	74.521dB	75.342dB	76.369dB	72.315dB
2000Hz	82.678dB	76.418dB	74.662dB	80.381dB	79.85dB	73.035dB	75.264dB	73.46dB
3000Hz	87.478dB	83.915dB	79.708dB	73.351dB	75.155dB	72.745dB	75.813dB	74.569dB
4000Hz	81.39dB	76.355dB	78.754dB	74.55dB	73.671dB	73.712dB	74.483dB	76.407dB
5000Hz	84.631dB	79.479dB	78.242dB	77.622dB	76.696dB	74.659dB	75.785dB	73.88dB
6000Hz	86.794dB	82.512dB	81.966dB	80.406dB	78.368dB	76.621dB	73.576dB	75.866dB
7000Hz	89.407dB	85.791dB	83.833dB	81.953dB	79.141dB	75.976dB	74.412dB	75.548dB
8000Hz	91.336dB	88.326dB	87.027dB	84.212dB	81.807dB	82.23dB	81.476dB	76.56dB
9000Hz	90.806dB	84.74dB	82.231dB	79.446dB	76.357dB	76.888dB	72.252dB	72.711dB
10000Hz	86.333dB	83.162dB	81.09dB	79.691dB	76.527dB	75.181dB	76.879dB	74.42dB
11000Hz	79.765dB	78.333dB	79.447dB	76.722dB	76.308dB	75.304dB	75.848dB	73.136dB
12000Hz	78.51dB	78.875dB	77.388dB	75.214dB	74.504dB	73.306dB	72.92dB	72.478dB
13000Hz	77.064dB	77.717dB	74.559dB	73.451dB	72.717dB	72.686dB	72.516dB	72.489dB
14000Hz	83.179dB	79.373dB	77.488dB	74.544dB	74.284dB	73.609dB	74.12dB	73.262dB
15000Hz	81.607dB	81.098dB	78.002dB	76.898dB	74.469dB	74.169dB	72.605dB	73.398dB
16000Hz	85.377dB	83.19dB	80.168dB	77.958dB	75.792dB	74.104dB	72.67dB	74.054dB
17000Hz	84.427dB	83.305dB	81.986dB	78.992dB	77.974dB	76.891dB	73.489dB	75.711dB
18000Hz	84.272dB	81.779dB	79.368dB	77.421dB	76.37dB	74.906dB	72.913dB	74.511dB
19000Hz	82.705dB	82.685dB	81.449dB	78.178dB	76.364dB	74.758dB	73.531dB	74.822dB
20000Hz	83.615dB	82.376dB	79.673dB	77.55dB	75.523dB	74.368dB	73.587dB	74.243dB

Data were collected under 20 seconds of fog with the same parameters used under 10 seconds of fog experiment. Table 3.15shows the data collected under 20 seconds of fog production.

Table 3.15 Sound Recorded During 20 Seconds of Fog Production as a Function of Distance Between the Transmitter and Receiver for Frequencies Between 50 to 20, 000 Hz and Intensity of Sound are Denoted in Decibel

20 SEC OF FOG	1ft	2ft	3ft	4ft	5ft	6ft	7ft	8ft
50Hz	72.867dB	72.814dB	73dB	72.275dB	72.095dB	72.914dB	72.396dB	72.879dB
100 Hz	84.415dB	79.244dB	77.966dB	78.054dB	77.29dB	76.603dB	75.542dB	75.133dB
150 Hz	91.899dB	86.842dB	83.309dB	77.788dB	72.827dB	72.291dB	73.601dB	73.441dB
200 Hz	88.048dB	75.536dB	80.481dB	84.27dB	83.467dB	79.963dB	75.516dB	76.568dB
250 Hz	84.371dB	76.021dB	78.338dB	80.22dB	78.432dB	73.193dB	76.84dB	76.251dB
300 Hz	81.985dB	81.061dB	78.126dB	74.987dB	78.333dB	76.714dB	73.845dB	72.6dB
350 Hz	84.885dB	75.048dB	77.911dB	79.762dB	76.695dB	75.539dB	74.208dB	75.612dB
400 Hz	86.395dB	80.118dB	77.738dB	75.834dB	78.812dB	78.496dB	75.576dB	72.077dB
450 Hz	83.095dB	81.475dB	73.835dB	77.902dB	77.001dB	72.478dB	72.371dB	75.111dB
500 Hz	84.756dB	77.721dB	82.015dB	75.943dB	74.416dB	79.374dB	74.46dB	73.394dB
550 Hz	84.489dB	77.219dB	76.562dB	75.323dB	73.116dB	73.374dB	73.903dB	72.339dB
600 Hz	80.556dB	79.264dB	73.675dB	74.002dB	75.487dB	73.314dB	75.721dB	74.179dB
650 Hz	83.486dB	75.302dB	75.398dB	72.797dB	77.722dB	77.427dB	74.678dB	72.802dB
700 Hz	80.957dB	79.968dB	74.826dB	73.601dB	75.667dB	74.605dB	75.579dB	76.022dB
750 Hz	81.806dB	77.08dB	75.206dB	74.828dB	74.713dB	72.004dB	77.526dB	76.264dB
800 Hz	80.834dB	75.28dB	72.865dB	74.592dB	71.386dB	72.316dB	73.237dB	74.6dB
850 Hz	82.848dB	79.276dB	76.964dB	76.444dB	72.911dB	73.784dB	72.646dB	72.747dB
900 Hz	83.331dB	78.016dB	75.364dB	78.678dB	71.551dB	72.69dB	73.847dB	72.556dB
1000 Hz	83.627dB	78.409dB	81.336dB	73.826dB	73.121dB	73.944dB	74.582dB	72.826dB
2000 Hz	83.762dB	77.687dB	76.648dB	79.373dB	78.189dB	73.311dB	73.574dB	72.993dB
3000 Hz	85.189dB	82.67dB	79.591dB	77.401dB	74.296dB	73.186dB	73.284dB	73.063dB
4000 Hz	81.709dB	79.675dB	78.788dB	77.624dB	73.772dB	74.952dB	76.548dB	73.549dB
5000 Hz	85.335dB	80.755dB	79.039dB	76.153dB	74.605dB	75.298dB	74.029dB	74.118dB
6000 Hz	86.775dB	85.052dB	82.858dB	78.775dB	78.223dB	76.38dB	77.134dB	77.181dB
7000 Hz	88.96dB	86.527dB	83.632dB	81.593dB	79.949dB	74.32dB	76.148dB	73.62dB
8000 Hz	87.01dB	86.081dB	86.749dB	82.807dB	81.104dB	80.295dB	79.658dB	79.154dB
9000 Hz	86.85dB	82.923dB	81.881dB	78.018dB	75.613dB	74.671dB	72.471dB	72.299dB
10000 Hz	86.558dB	82.694dB	81.244dB	79.999dB	75.987dB	74.028dB	76.657dB	72.373dB
11000 Hz	77.287dB	81.289dB	79.382dB	76.356dB	75.092dB	75.388dB	73.899dB	72.658dB
12000 Hz	76.149dB	75.1dB	76.67dB	74.051dB	73.428dB	72.399dB	72.964dB	72.255dB
13000 Hz	75.826dB	76.87dB	75.102dB	73.632dB	73.201dB	72.348dB	72.026dB	72.401dB
14000 Hz	81.56dB	81.07dB	77.652dB	74.363dB	74.11dB	73.573dB	73.242dB	73.147dB
15000 Hz	80.212dB	81.553dB	78.398dB	76.796dB	74.54dB	73.973dB	73.574dB	73.362dB
16000 Hz	85.13dB	83.298dB	80.792dB	78.016dB	75.738dB	74.101dB	73.179dB	73.414dB
17000 Hz	82.673dB	83.366dB	81.503dB	78.249dB	76.616dB	76.37dB	74.051dB	74.939dB
18000 Hz	82.758dB	82.555dB	79.57dB	77.425dB	75.278dB	74.129dB	74.199dB	73.221dB
19000 Hz	83.324dB	83.738dB	81.711dB	78.348dB	76.047dB	74.699dB	74.209dB	74.051dB
20000 Hz	82.039dB	82.999dB	79.507dB	77.106dB	74.002dB	74.11dB	73.122dB	73.614dB

Data were collected under 30 seconds of fog with the same parameters used under no fog experiment. Table 3.15 shows the data collected under 30 seconds of fog production.

Table 3.16 Sound Recorded During 30 Seconds of Fog Production as a Function of Distance Between the Transmitter and Receiver for Frequencies Between 50 to 20, 000 Hz and Intensity of Sound are Denoted in Decibel

30 SEC OF FOG	1ft	2ft	3ft	4ft	5ft	6ft	7ft	8ft
50 Hz	72.5 dB	72.858 dB	72.644 dB	72.103 dB	72.276 dB	72.918 dB	72.752 dB	71.928 dB
100 Hz	83.786 dB	79.939 dB	77.999 dB	77.862 dB	77.644 dB	76.305 dB	75.479 dB	74.405 dB
150 Hz	91.216 dB	87.263 dB	82.518 dB	76.841 dB	72.707 dB	72.875 dB	71.967 dB	72.406 dB
200 Hz	83.272 dB	75.754 dB	81.097 dB	84.159 dB	83.095 dB	78.88 dB	75.417 dB	74.994 dB
250 Hz	83.442 dB	76.09 dB	78.512 dB	79.821 dB	78.174 dB	72.613 dB	73.265 dB	73.484 dB
300 Hz	81.699 dB	81.849 dB	77.233 dB	75.678 dB	77.684 dB	75.669 dB	74.349 dB	74.688 dB
350 Hz	82.998 dB	76.938 dB	78.344 dB	79.619 dB	76.715 dB	75.806 dB	72.887 dB	71.734 dB
400 Hz	83.746 dB	81.877 dB	76.273 dB	75.935 dB	74.177 dB	77.729 dB	74.992 dB	73.852 dB
450 Hz	82.734 dB	82.155 dB	74.752 dB	74.594 dB	73.423 dB	72.941 dB	72.936 dB	72.554 dB
500 Hz	81.73 dB	79.55 dB	77.995 dB	75.162 dB	75.908 dB	74.537 dB	73.88 dB	72.597 dB
550 Hz	82.615 dB	79.38 dB	76.188 dB	76.544 dB	73.612 dB	73.139 dB	74.466 dB	71.374 dB
600 Hz	79.874 dB	78.667 dB	74.347 dB	72.516 dB	75.506 dB	72.883 dB	75.715 dB	71.462 dB
650 Hz	81.714 dB	74.783 dB	74.255 dB	74.277 dB	76.931 dB	73.526 dB	74.087 dB	73.913 dB
700 Hz	80.16 dB	79.924 dB	75.366 dB	72.829 dB	75.493 dB	74.665 dB	74.423 dB	74.593 dB
750 Hz	81.666 dB	77.028 dB	74.724 dB	73.181 dB	74.265 dB	73.123 dB	72.085 dB	74.323 dB
800 Hz	80.325 dB	75.615 dB	72.837 dB	75.176 dB	73.3 dB	74.81 dB	73.702 dB	73.337 dB
850 Hz	82.316 dB	79.388 dB	76.233 dB	75.919 dB	75.069 dB	74.437 dB	73.209 dB	72.778 dB
900 Hz	82.409 dB	78.531 dB	75.806 dB	78.703 dB	72.731 dB	72.549 dB	75.502 dB	76.693 dB
1000 Hz	83.148 dB	78.043 dB	77.21 dB	75.315 dB	74.335 dB	75.334 dB	76.338 dB	73.177 dB
2000 Hz	82.353 dB	77.016 dB	76.622 dB	81.179 dB	76.928 dB	74.948 dB	76.454 dB	73.077 dB
3000 Hz	86.626 dB	82.594 dB	80.535 dB	78.816 dB	74.352 dB	73.58 dB	75.28 dB	73.35 dB
4000Hz	82.026 dB	77.787 dB	75.756 dB	76.693 dB	75.262 dB	74.715 dB	73.818 dB	74.914 dB
5000Hz	84.537 dB	80.891 dB	80.662 dB	77.896 dB	75.336 dB	73.406 dB	73.305 dB	74.493 dB
6000Hz	86.553 dB	83.51 dB	81.777 dB	80.098 dB	78.772 dB	77.511 dB	76.576 dB	74.964 dB
7000Hz	89.405 dB	84.257 dB	83.719 dB	80.636 dB	78.672 dB	75.788 dB	76.164 dB	74.811 dB
8000Hz	91.356 dB	87.884 dB	86.913 dB	83.443 dB	81.239 dB	80.629 dB	80.468 dB	78.303 dB
9000Hz	90.017 dB	83.504 dB	80.786 dB	76.609 dB	76.221 dB	72.831 dB	76.701 dB	74.668 dB
10000Hz	86.666 dB	82.249 dB	82.862 dB	79.957 dB	76.769 dB	77.621 dB	73.086 dB	75.111 dB
11000Hz	77.951 dB	79.439 dB	77.653 dB	76.892 dB	75.161 dB	74.622 dB	74.099 dB	74.088 dB
12000Hz	79.874 dB	78.519 dB	75.78 dB	74.696 dB	73.207 dB	72.815 dB	73.003 dB	72.814 dB
13000Hz	78.236 dB	77.242 dB	74.531 dB	73.365 dB	72.429 dB	73.275 dB	72.496 dB	73.111 dB
14000Hz	82.836 dB	80.798 dB	77.762 dB	75.237 dB	74.143 dB	74.789 dB	72.647 dB	73.504 dB
15000Hz	81.897 dB	81.906 dB	78.356 dB	76.427 dB	75.064 dB	73.054 dB	74.119 dB	73.655 dB
16000Hz	84.932 dB	83.612 dB	79.209 dB	76.575 dB	75.31 dB	75.507 dB	74.523 dB	73.802 dB
17000Hz	83.858 dB	83.226 dB	81.325 dB	78.424 dB	76.164 dB	75.145 dB	74.933 dB	75.05 dB
18000Hz	84.751 dB	82.201 dB	79.189 dB	77.348 dB	75.072 dB	74.523 dB	73.269 dB	74.034 dB
19000Hz	82.791 dB	83.538 dB	81.198 dB	78.401 dB	76.259 dB	74.897 dB	74.088 dB	74.042 dB
20000Hz	83.625 dB	82.427 dB	79.377 dB	76.835 dB	74.9 dB	74.591 dB	73.96 dB	73.764 dB

Finally, data were collected under 40 seconds of fog with the same parameters used under no fog experiment. Table 3.17 shows the data collected under 40 seconds of fog production.

Table 3.17 Sound Recorded During 40 Seconds of Fog Production as a Function of Distance Between the Transmitter and Receiver for Frequencies Between 50 to 20, 000 Hz and Intensity of Sound are Denoted in Decibel

40 SEC OF FOG	1ft	2ft	3ft	4ft	5ft	6ft	7ft	8ft
50 Hz	72.704 dB	72.872 dB	72.159 dB	72.469 dB	72.998 dB	72.847 dB	72.995dB	71.181dB
100 Hz	83.381 dB	78.71 dB	78.288 dB	78.64 dB	75.016 dB	75.894 dB	74.282dB	75.067dB
150 Hz	91.603 dB	84.53 dB	82.305 dB	77.688 dB	76.176 dB	75.61 dB	75.514dB	74.306dB
200 Hz	87.458 dB	75.369 dB	82.445 dB	84.976 dB	83.836 dB	79.49 dB	76.611dB	75.784dB
250 Hz	84.127 dB	78.784 dB	82.606 dB	83.679 dB	76.669 dB	73.662 dB	77.754dB	77.006dB
300 Hz	78.04 dB	80.275 dB	73.701 dB	78.129 dB	78.029dB	74.848 dB	74.66dB	75.337dB
350 Hz	84.621 dB	76.895 dB	73.991 dB	75.554 dB	74.561 dB	79.174 dB	74.538dB	73.491dB
400 Hz	83.119 dB	81.424 dB	73.769 dB	75.563 dB	75.697 dB	75.626 dB	73.243dB	72.843dB
450 Hz	82.338 dB	79.749 dB	77.13 dB	76.143 dB	74.338 dB	73.349dB	74.47dB	75.751dB
500 Hz	81.765 dB	80.438 dB	79.099 dB	73.517 dB	76.969 dB	75.241 dB	73.518dB	73.373dB
550 Hz	84.075 dB	77.899 dB	76.922 dB	80.311 dB	75.414 dB	74.76 dB	73.376dB	73.984dB
600 Hz	84.709 dB	78.304 dB	76.536 dB	73.638 dB	74.673 dB	73.39 dB	73.489dB	74.771dB
650 Hz	80.733 dB	79.176 dB	78.549 dB	76.403 dB	76.478 dB	73.33 dB	74.814dB	73.636dB
700 Hz	81.81 dB	78.47 dB	74.936 dB	73.26 dB	75.841dB	73.882 dB	75.223dB	73.777dB
750 Hz	79.775 dB	79.954 dB	75.279 dB	73.387 dB	74.072 dB	75.964 dB	74.871dB	74.319dB
800 Hz	80.022 dB	78.683 dB	75.554 dB	75.099 dB	73.395 dB	74.957 dB	75.39dB	75.557dB
850 Hz	84.629 dB	74.833 dB	79.959 dB	74.464 dB	73.899 dB	75.725 dB	74.394dB	73.391dB
900 Hz	83.601 dB	81.285 dB	74.33 dB	78.247 dB	74.764 dB	77.47dB	73.406dB	73.053dB
1000 Hz	84.15 dB	84.194 dB	79.821 dB	76.898 dB	78.235 dB	74.114 dB	72.635dB	72.066dB
2000 Hz	81.069 dB	79.04 dB	74.965 dB	77.593 dB	76.559dB	73.564 dB	74.118dB	72.481dB
3000 Hz	86.35 dB	81.335 dB	81.214 dB	77.319 dB	76.36 dB	74.926 dB	75.618dB	73.083dB
4000 Hz	82.59 dB	77.106 dB	76.704 dB	76.84 dB	73.855 dB	73.379 dB	73.855dB	73.49dB
5000 Hz	83.811 dB	79.408 dB	79.201 dB	76.945 dB	75.836 dB	74.939 dB	74.726dB	73.467dB
6000 Hz	86.877 dB	84.076 dB	81.31 dB	76.58 dB	77.423 dB	77.316 dB	74.948dB	75.135dB
7000 Hz	87.628 dB	84.395 dB	81.892 dB	79.336 dB	78.881 dB	77.169 dB	73.725dB	72.851dB
8000 Hz	89.561 dB	88.483 dB	84.893 dB	82.716 dB	80.805dB	79.187 dB	76.531dB	74.273dB
9000 Hz	88.967 dB	85.365 dB	81.393 dB	78.254 dB	75.676 dB	74.284dB	73.769dB	73.648dB
10000 Hz	87.615 dB	83.763 dB	80.107 dB	78.363 dB	76.249 dB	74.203 dB	74.962dB	72.701dB
11000 Hz	79.552 dB	79.596 dB	77.126 dB	76.194 dB	75.897 dB	74.134 dB	74.252dB	73.119dB
12000 Hz	78.47 dB	78.133 dB	76.112 dB	74.651 dB	73.629 dB	72.196 dB	73.033dB	73.181dB
13000 Hz	77.582 dB	77.263 dB	74.424 dB	74.408 dB	73.827 dB	72.576 dB	73.405dB	73.174dB
14000 Hz	83.042 dB	79.372 dB	76.56 dB	74.938 dB	74.553 dB	73.068 dB	73.298dB	73.561dB
15000 Hz	81.514 dB	80.307 dB	78.177 dB	75.38 dB	74.668 dB	72.803dB	73.649dB	73.26dB
16000 Hz	83.419 dB	82.214 dB	77.697 dB	76.093 dB	74.815 dB	73.092 dB	73.643dB	72.887dB
17000 Hz	82.945 dB	82.346 dB	79.628 dB	78.039 dB	76.594 dB	73.485 dB	73.956dB	73.689dB
18000 Hz	82.727 dB	80.341 dB	77.923 dB	76.117 dB	74.875 dB	73.164 dB	73.172dB	73.273dB
19000 Hz	82.139 dB	82.509 dB	79.738 dB	76.746 dB	75.533 dB	73.018 dB	73.05dB	73.477dB
20000 Hz	82.813 dB	80.829 dB	79.078 dB	75.671 dB	74.754 dB	73.573 dB	73.892dB	73.277dB

3.2.2 Graphs of Sound Experiment

Tables 3.13 to 3.17 shows the data collect from no fog to different production level of the fog in seconds. Graphs 3.41 to 3.45 shows the graphical representation of the data collected in tables 3.13 to 3.17. Graph 3.46 shows the comparison of the data collected from the sound meter and the system developed in this project.

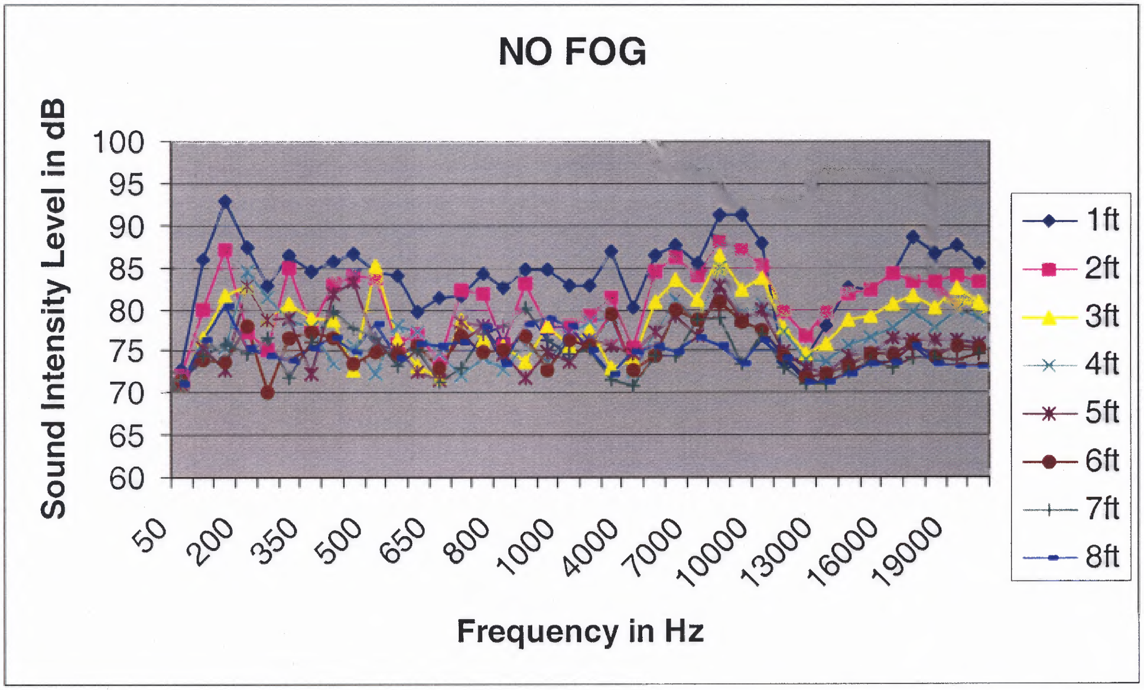


Figure 3.40 Sound intensity level, in decibel (db), versus sound frequencies for control (no fog) condition with varying distances (feet).

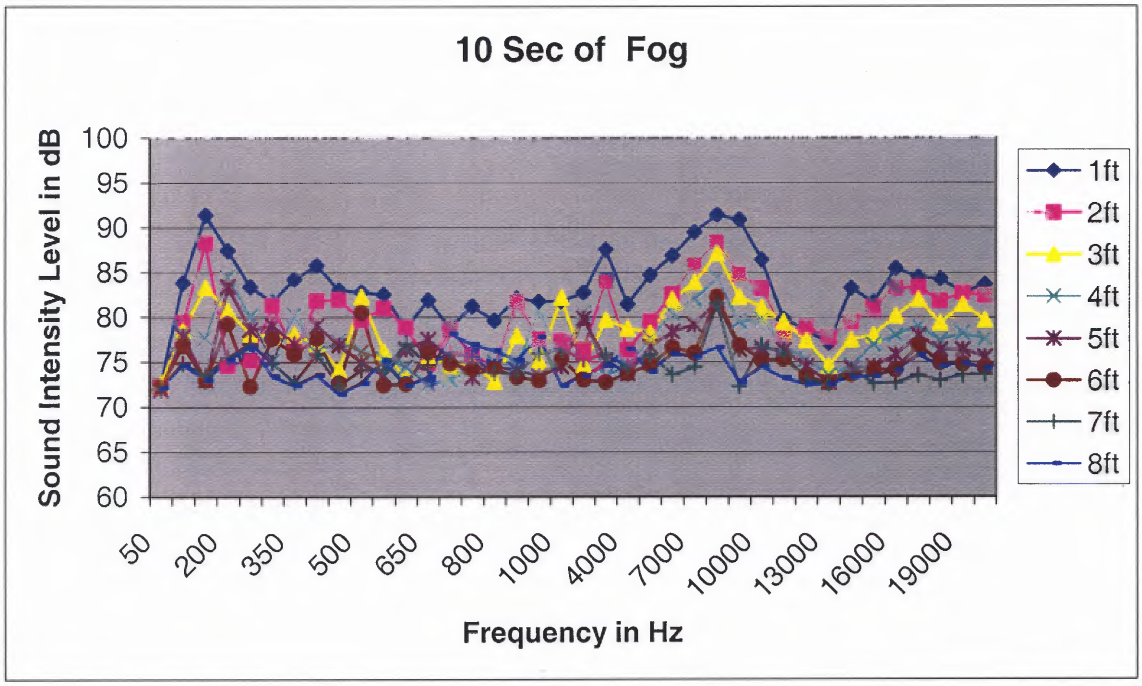


Figure 3.41 Sound intensity level, in decibel (db), versus sound frequencies for 10 seconds condition with varying distances (feet).

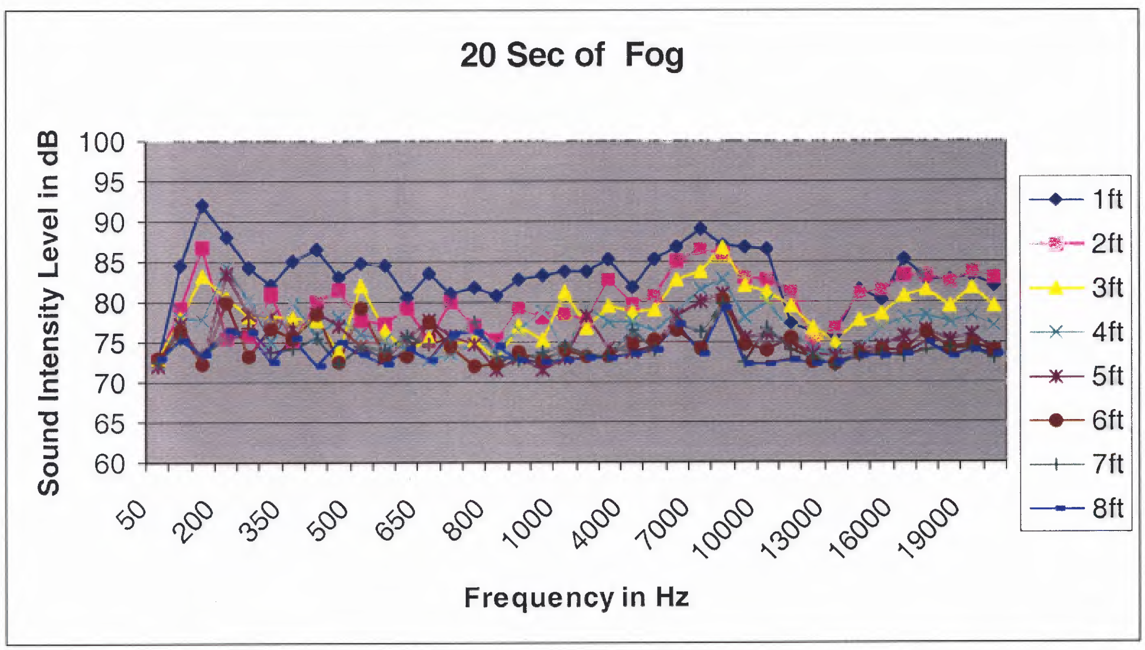


Figure 3.42 Sound intensity level, in decibel (db), versus sound frequencies for 20 seconds condition with varying distances (feet).

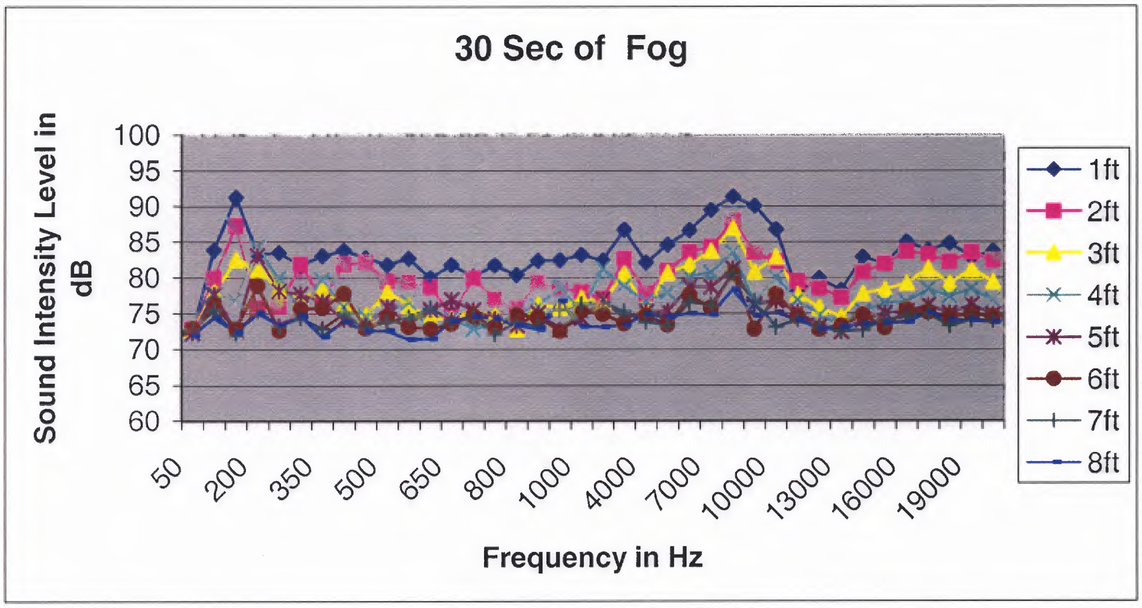


Figure 3.43 Sound intensity level, in decibel (db), versus sound frequencies for 30 seconds condition with varying distances (feet).

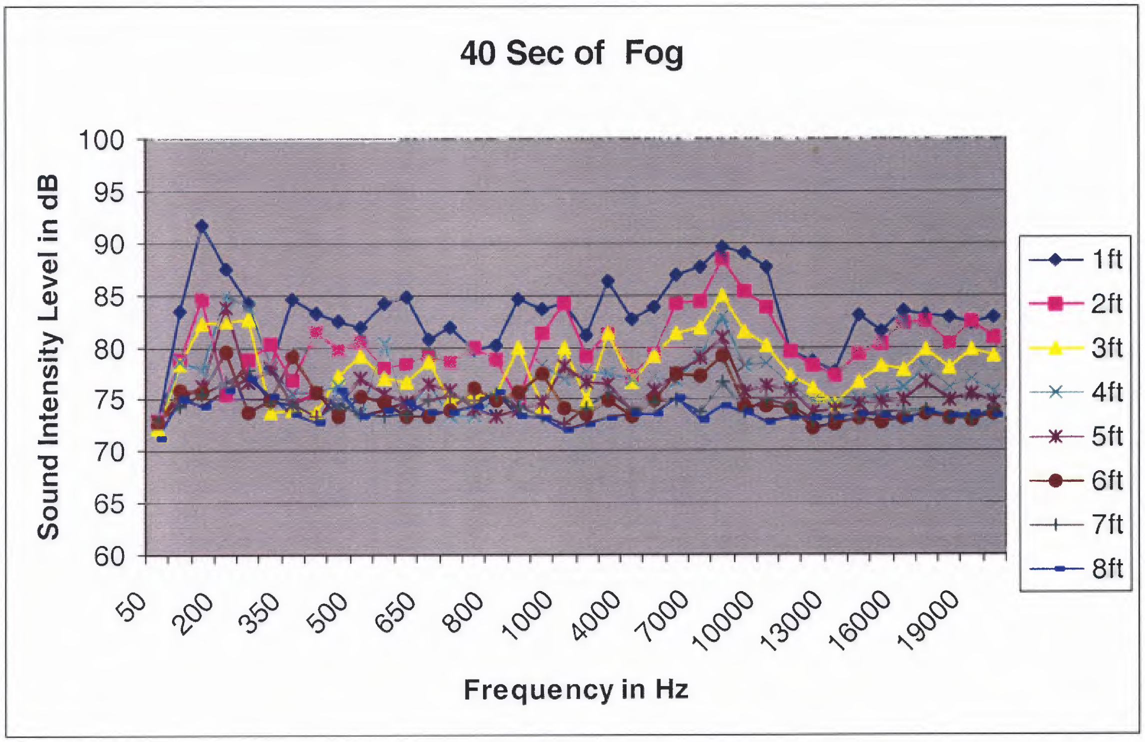


Figure 3.44 Sound intensity level, in decibel (db), versus sound frequencies for 40 seconds condition with varying distances (feet).

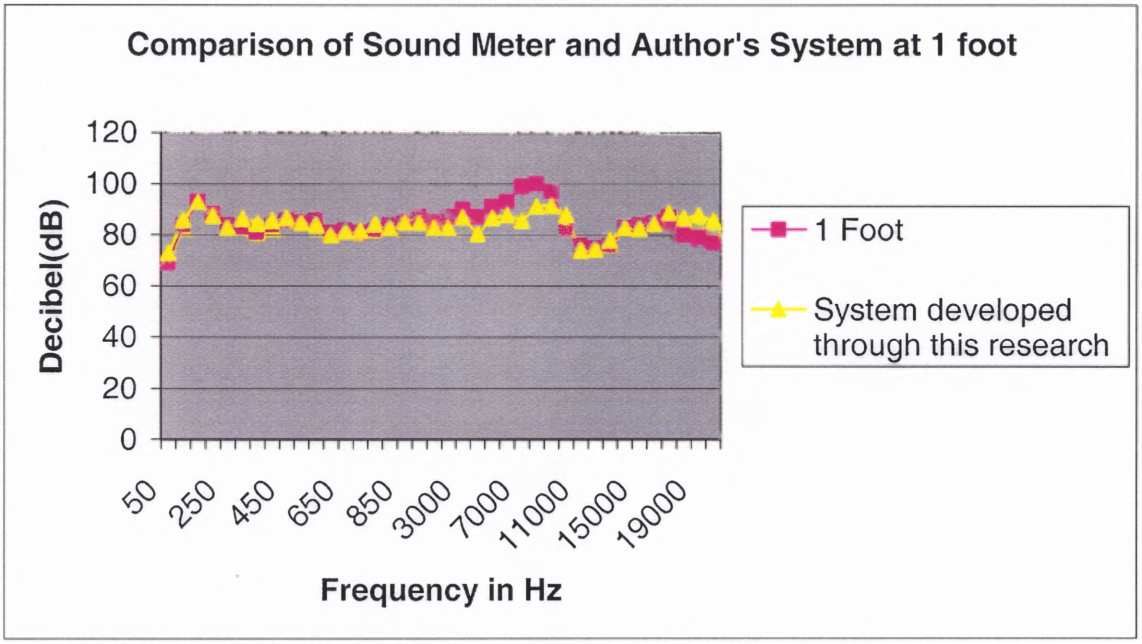


Figure 3.45 Validation through comparison of sound meter purchased through Radio Shack and the system developed from this research when the transmitter and receiver were 1 foot apart. Results are within +/- 2 dB.

There was no substantial decrement or increment noticed in the results of the sound experiments under fog at different production level (in seconds) compared to the control (no fog). For the validation of the system a sound meter, manufactured by Radio Shack, was used. Looking at figure 3.46, which shows the comparison of the developed system in this research and the Radioshack measurements, there is not substantial difference recognized between two systems. According to the author, the experimental room was not large enough to see major difference in the measurements of the sound experiment. Graph 3.46 shows the results obtained by comparing no fog to 40 seconds of fog production. There is substantial lost in intensity of sound frequency under fog condition than in the air medium.

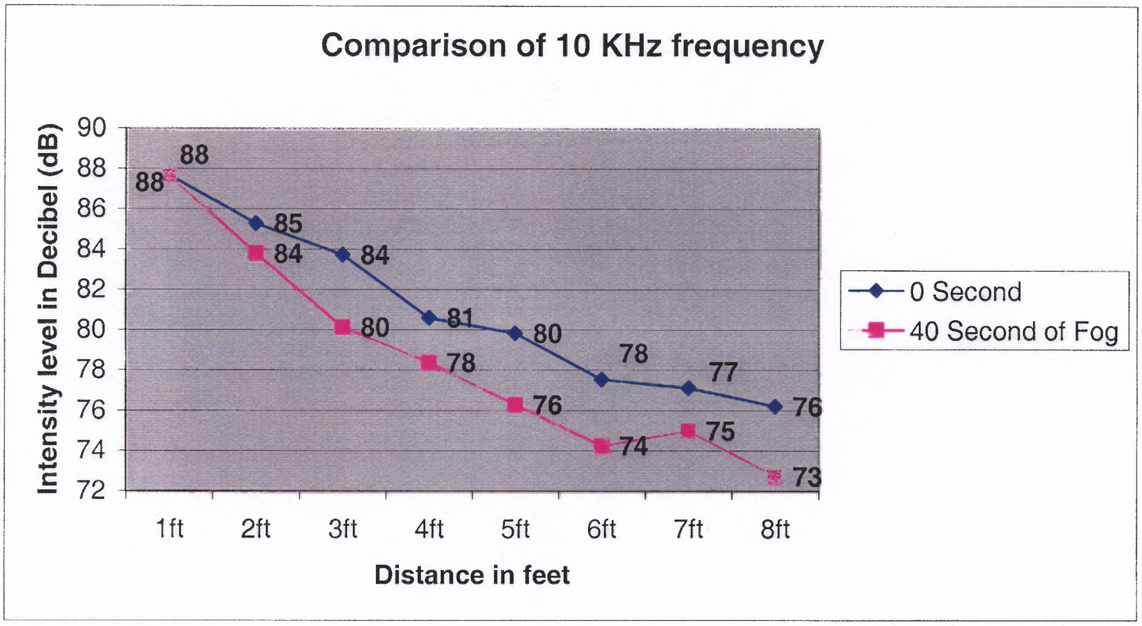


Figure 3.46 Comparison of 10 KHz frequency in no fog and 40 seconds of fog medium. Sound intensity is less attenuated in the fog medium compared to air medium. 10 KHz frequency was chosen for the analysis because it is in the middle of the audible range (20 Hz to 20 KHz).

CHAPTER 4

DISCUSSION

This section discussed the data shown in the graphs and tables from chapter 3. Section 4.1 discussed the light experimentation whereas section 4.2 discusses the sound experiment data. Discussion of sound and light experiment is needed for a better understanding of the data provided in the Result section.

4.1 Light Experimentation

After the data of the light experiment were normalized according to the sensitivity of the chromo meter, data were divided in to three main sections: data grouped by color, time of fog production, and distance between the transmitter and receiver.

4.1.1 Data by Color

Data collected from the light experiment were grouped by seven different colors of light: red, orange, yellow, green, purple, blue, and white. The intensity of each color was inversely proportional to the fog production time (figure 3.16 – 3.22). Furthermore, the light intensity measured by the chromo meter was inversely proportional for each fog production times (measured in seconds) (figure 3.23 – 3.28). Figure 3.16 shows that as red light travel further distances, the intensity of light decreases. For example, when the transmitter and receiver were 2 feet apart, the intensity of red light measured during the control was 16,467 Lux. When the distance between the transmitter and receiver was 8 feet the intensity of red light was 735 Lux, which is 96% less in intensity. Using the same parameter, these data show the orange light was reduced by 95% (Figure 3.17), yellow light by 95% (Figure 3.18), green light by 96% (Figure 3.19), purple light by 95% (Figure 3.20), blue light by 96% (Figure 3.20), and white light reduced by 95% (Figure 3.21). Another trend found in the data was that the time of fog production was inversely related to the intensity of light. For example, yellow light intensity (Figure 3.18) measured at a distance of 2 feet between transmitter and receiver during the control was measured as 90,121 Lux and for 10 seconds of fog production for the same distance the intensity was 1201 Lux which is 99% of loss in the intensity. Even 8 seconds of fog reduced the yellow light intensity by 98% with virtually zero visibility. Similarly, all the colors show 99% of reduction in the intensity for 10 seconds of fog production for a distance between the transmitter and receiver of 8 feet which means the fog affects all the colors in a similar manner resulting in zero visibility conditions.

4.1.1 Data by Density

The data collected from the light experiment were analyzed using different methods. Data was grouped by the amount of fog production, for the control (no fog production), 2, 4, 6, 8, and 10 seconds of fog production. The graphs shown in section 3.1.2.1 gives the excellent details pertaining each color of lights. The graphs (Figure 3.23 – 3.28) effectively show the relationship between light transmission for the control and different densities of fog environments. Figure 3.23 to 3.28 are the graphs for all the colors under no fog and varying fog production in seconds. These graphs show as density of fog increases the intensity of light decreases where the visibility declines. Figure 3.29 to 3.33 shows the percentage lost in the transmission of light from the control to various fog production time at different distances between the transmitter and receiver. For example, in Figure 3.29, which is the percentage difference in intensity from no fog to 2 seconds of fog production, the red light intensity level decreased by 55% when the transmitter and receiver were 2 feet apart; however, for the same condition of fog production the light intensity decrease by 15% when the transmitter and receiver were 8 feet apart. This analysis investigated two parameters 1) for a given wavelength and the same distance between transmitter and receiver how did the amount of fog production influence results and 2) for a given wavelength and fog production how did the distance between the transmitter and receiver influence the results. In figure 3.29 the amount of fog production was kept constant and the variable of interest was the distance between the transmitter and receiver. For example, for the orange color there was a 50% reduction in signal intensity at 2 feet and 21 % decrease at 8 feet, yellow decreased 64% at 2 feet and 21% decrease at 8 feet, green decreased 61% at 2 feet and 21% decrease at 8 feet, purple showed a 50% decrease at 2 foot and 21.12% decrease at 8 feet, and blue decrease by 55% at 2 foot and 19% at 8 foot distance. Similarly, Figure 3.29 to 3.32 shows the percentage lost from no fog to fog conditions. Figure 3.31 shows 98% lost at 2 foot distance and 94 to 95 percentage lost at 8 foot distance for red light. However, figure 3.33 shows a 99% reduction, for all colors, when the transmitter and receiver were 2 feet apart and at 98% reduction when the transmitter and receiver were 8 feet distance. Which means there was 99% reduction in the transmission of light at 2 feet distance (compare to 2 feet distance with no fog) and 98% reduction at 8 feet (compare to 8 feet distance with no fog) when 10 seconds of fog was deployed. Data show there is virtually no visibility for eight seconds of fog production in a 11x11x8 feet room when the distance between the transmitter and receiver was 8 feet. Based on these data, the fog machine was not run for more than 10 seconds during the visibility studies because after 10 seconds the visibility declined by 99%, so increasing the fog production time would give constant results.

4.1.2 Data by Distance

Sub Section 3.1.2.2 shows the graphs which are grouped by distance between the transmitter and receive in feet starting from 2 feet distance, incremented by 1 foot, up to 8 feet. Figure 3.33 to 3.39 shows the percentage lost from no fog to different fog production times for a given distance in feet. For example, Figure 3.33 shows the percentage lost for a 2 feet distance from the control to various fog production times. There was a 99% reduction in signal intensity when the fog machine operated for 10 seconds of fog for all the distances. Looking carefully at the graphs, the green light has the most loss in percentage among other six different colors of lights for all the distances at varying production of fog. For example, at 2 feet distance (Figure 3.33), the largest percentage lost is 64% which is green light. Similarly, for 3 feet distance (Figure 3.34) most percentage decrease is 57% for green, at 4 feet distance most decreased is 46% (Figure 3.35) which is green, at 5 feet distance is 38%(Figure 3.36), at 6 feet distance is 28% (Figure 3.37), at 7 feet distance is 26%(Figure 3.38), and at 8 feet distance is 21% decrease in green light. These graphs show that, as density of fog increases, the percentage lost increases as well for a given distance. These graphs also show that between 6 seconds to 10 seconds of fog production there is not much difference in the percentage of intensity decrease, (the intensity is lost from 95% to 99%).

4.2 Sound Experiment

Sound data were recorded by a microphone and this research created a custom Lab VIEW program to automatically digitize and save data in to Excel files. Section 3.2.1 shows the table of the data collected in the sound experiment. Section 3.2.2 shows the graphs of the data shown in the tables of section 3.2.1. Figure 3.40 to 3.43 show a similar trend which is, as distance increases the sound intensity level (db) decreases for the control environment as well as the various densities of fog environments. For example, in figure 3.41 when the transmitter and receiver were one foot apart, the intensity in decibels calculated were higher than the intensity measured when the transmitter and receiver were 8 feet apart. The percentage difference between no fog and various density of fog is very small, about 5%. Figure 3.40 to 3.43 shows the 38 different sound files (50Hz to 20,000Hz) at distances from 1 foot to 8 feet (increment by 1 foot) under no fog, 10 seconds of fog, 20 seconds of fog, 30 seconds of, and 40 seconds of fog. Since the change in intensity level from no fog to different density of fog was very minimal, this research did not obtain more data after 40 seconds of fog production. The small change in intensity level shows that it required many seconds of fog production to observe substantial differences in the sound frequencies.

Sound frequency attenuated less in a fog medium than in the air medium. For example, Figure 3.46 shows the comparison of no fog to 40 seconds of fog production of 10 KHz frequency. At 8 feet of distance under no fog condition, the intensity of 10 KHz frequency is 76 dB. However, at 8 feet of distance under 40 seconds of fog production, the intensity of 10 KHz frequency is 73 which shows that sound intensity decreases as fog production increases.

CHAPTER 5

CONCLUSIONS

The main goal of this research was to study the transmission of sound and light energies under fog condition and compare it with no fog condition (the control). There were thirty eight different sound frequencies studied, ranging from 50 Hz to 20,000 Hz, utilized in the sound experiments. There were seven different colors; red, orange, yellow, green, purple, blue, and white investigated during the light experiment. Sound results measured by taking certain factors in mind such as: ensuring that there is no delay between the production of sound and the recording of sound, the data collected from the microphone are the data for the frequencies played by the speaker, creation of a LabVIEW program that records different sound files simultaneously. Furthermore, controlling the light and sound energies from a location, other than the experiment room, was a crucial aspect of this research as well. Due to fog in the experiment room, the mobility of the sensors from one distance to another would be difficult so all the sensors were controlled by an operator outside the experiment room. Fans needed to be placed in a way that the fog evacuates faster. Fog does not travel like smoke so it needs to be pushed from one side and pulled from the other side to be evacuated. Therefore one fan was placed in the bottom, to push the fog by external air, and one fan was placed at the top corner of the room to pull the fog out of the room.

After analyzing the results carefully, the light is more affected by the fog transmission compared to sound. Light transmission decreases as distance increases. Light intensity also decreases in the medium when fog was present compared to an air medium. Light transmission is almost zero at 8 seconds of fog production.

Sound recorded data were verified with the sound meter from the Radio Shack with + or – 2% error compared to the experimental system generated during this research. Sound transmission decreases as distance increases, although fog did not have a substantial effect on the transmission of sound in a 11x11x8 foot room. Sound decreases by 5% in the environment when there was 40 seconds of fog production compared to the control condition when the microphone was 1 foot to 8 feet apart (Figure 3.46). Sound intensity decreases as fog production increases.

In the thesis, there was no human interaction with the fog. The sound and light was studied through the sensors and this should be verified with human data by running human subjects. Data collected from the light and sound sensors during this investigation should be compared to human data. It is very interesting to find out whether ECG (Electrocardiogram), EMG, and the respiratory system of humans also are affected by different fog mediums compared to controls. Also in the sound experiment, data can be analyzed under hours of fog production for distances of 1 to 8 feet between the transmitter and receiver. Synthetic fog can be further studied to determine if it has any other effects on the human body than the ones which are already known, such as skin irritation and asthma [4].

APPENDIX A

FRONT PANEL VIEW OF SOUND EXPERIMENT

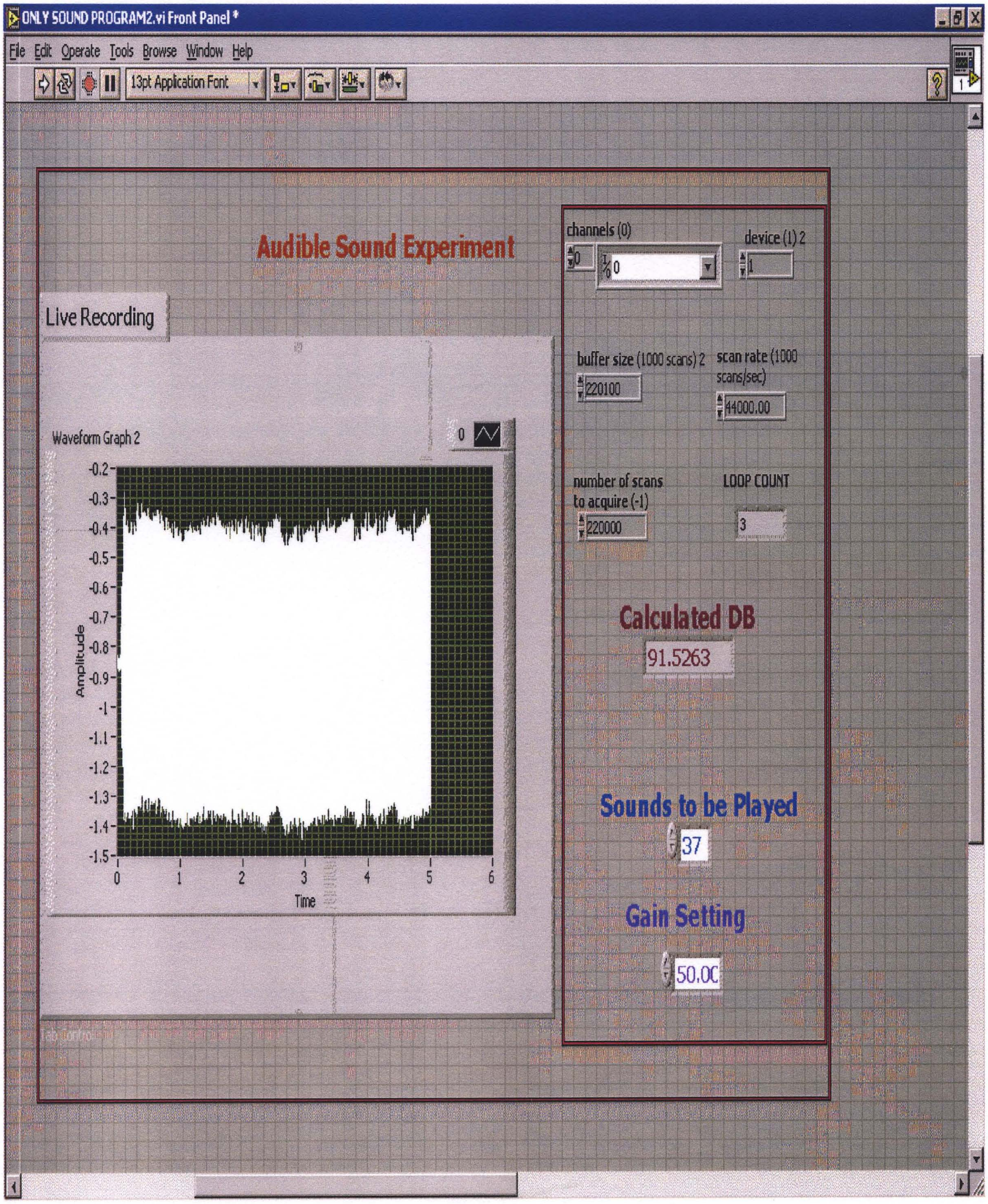


Figure A.1 Front panel view of the sound experiment.

APPENDIX B

BLOCK DIAGRAM OF THE AUDIBLE SOUND EXPERIMENT

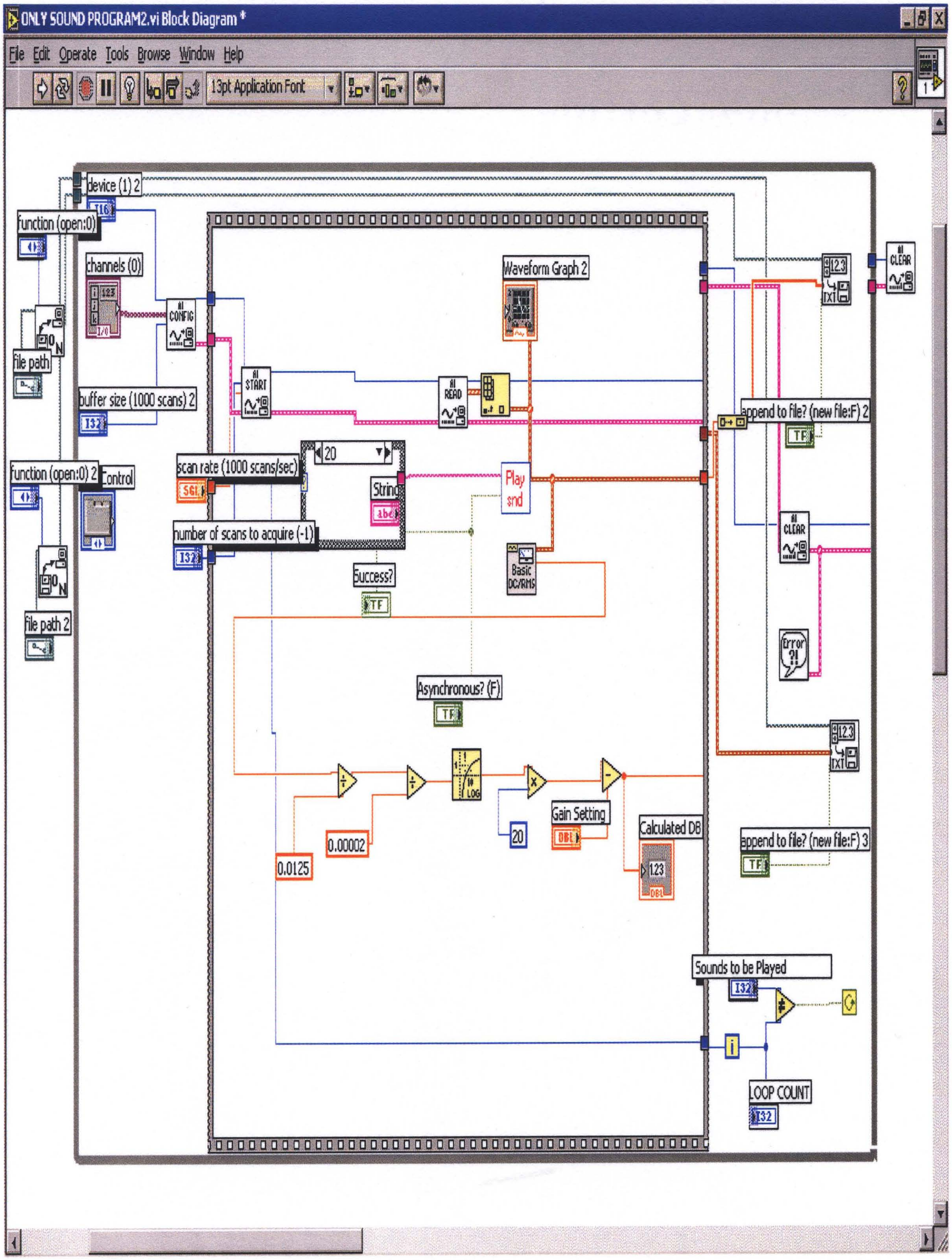


Figure B.1 Block diagram of the sound experiment.

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