GROWTH DEPENDENT LED LIGHTING CONTROL SYSTEM FOR LETTUCE THROUGH IMAGE PROCESSING USING ANFIS

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In Partial Fulfilment of the Course Requirements for the Degree of

Bachelor of Science in Electronics Engineering

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The Researchers

ABSTRACT

Proper cultivation of plants requires proper attention of supplying its 5 basic needs namely water, soil, space, air and especially light. More satisfactory, sufficient control of the amount of light output needed by the plants can help maximize its growth quality and further increase the speed of its cultivation faster than that of just ordinary sunlight. Based on numerous studies, controlling the red to blue ratio of the light accounts for optimum growth.

In this study, a growth dependent LED lighting control system was developed and implemented in a controlled environment chamber. This lighting system will provide the light necessities required for each stage of the crop, for which it is the Photosynthetically Active Radiation illuminated by the LED. It comprises of a vision system that utilizes image processing, based on the captured image by the C922 HD camera, in order to extract features that are correlated to the cultivation period of the lettuce plant. The gathered data will be inputted to the ANFIS algorithm wherein it will output the optimum lighting conditions for the current stage of the plant.

The comparison of the conventional setup that uses sunlight and the controlled lighting setup shows a significant difference in canopy area growth rate, height growth rate and the total number of leaves. The results show that the plant is 13.76% higher under controlled lighting, 24.46% in canopy area and 14.83% more leaves. The Principal Component Analysis shows that the lighting affects the growth above all other parameters. Thus, the designed chamber effectively shows the advantage of indoor farming over conventional farming.

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CHAPTER 1

THE PROBLEM AND ITS SETTING

1.1 Introduction

The world population grows constantly, and a greater number of individuals these days choose to stay in urban areas rather staying in the countryside. Urbanization influences the modern lifestyle, particularly, dietary patterns. According to an estimation of the Food and Agriculture Organization, all of the living human beings around the world in 2050 shall extend up to 9.73 billion of people. From 30 years before, a greater number of people reside in country territories leaving 40 percent only in certain urban areas. As the equalization between urban and rural areas has become particularly different, fifty-four percent of the global population is now urban. In 2015, the United Nations predicted that about 66 percent of the total population resides in nonrural cities. These progressions drove to the great impact on food production and consumption. Agriculture is the primary industry in most rural areas. On the other hand, higher income in urban areas leads to increase in demand for processed foods. With more people living in urban areas, fewer people work in agriculture and food production declines as the food consumption increases (Food and Agriculture Organization of the United Nations, 2017).

Controlled environment agriculture is a type of farming that sustains the growth optimization of the whole stages of development of the crop inside a closed environment. Issues like resource scarcity and climate change which contributes to the stress in conventional farming practices drives the CEA to take action. Controlled variables for crops consist of accumulation of nutrients, heat amount and light radiated, carbon dioxide and humidity. Controlled environment agriculture reduces water use, pesticide and fertilizer use. Differentiating from conventional farming, the controlled environment agriculture produces more capacity from similar land areas (Controlled Environment Agriculture, n.d.).

1.2 Background of the Study

Urban agriculture is a form of farming within urban areas. Unlike conventional rural agriculture, urban agriculture suffers issues like limited space, pollution, and the limited amount of natural lighting (Urban Agriculture, n.d.). In this case, urban agriculture mostly occurred in controlled environments that maintain the necessary amount of heat, nutrient absorption, radiated light, humidity, carbon dioxide, H2O and levels of pH for crop production (Controlled Environment Agriculture (CEA), n.d.).

Plants generate food and energy through photosynthesis for its growth and cellular respiration (Photosynthesis in Plants, n.d.). Photosynthesis utilizes energy from the radiation of the sun in order to produce glucose from carbon dioxide and H2O (Overview of Photosynthesis, n.d.). Plants in field receives natural light from the sun that has a wide spectrum of visible light that ranges from 400 to 700 nm of wavelength (The Sun & its Energy, n.d.). However, specific color ranges of light are only utilized by plants to achieve photosynthesis. This color ranges happens more often in red and blue light beams but not so much in green light beams. Light intensity also affects the process of photosynthesis. Higher light intensity increases the rate of photosynthesis while the cause of lesser amount of photosynthetic rate is the lesser amount of the intensity from light (Amrita Vishwa Vidyapeetham, n.d.).

In 1998, Albright et al. of Cornell University developed an algorithm called LASSI (Light and Shade System Implementation) that provides a management of auxiliary lighting with adjustable shades in order for a steady and stable daily light integral to be reached. Shade control is necessary for many crops such as lettuce suffers physiological disorder when received 10-20% more light radiation in either 2 or 3 days straight and quickly develops. Another research conducted by Albright et al. at Cornell University in 2007 that led them to a second algorithm (CO_2 LASSI) that examines a control mixture between a scope of light and carbon dioxide for the accompanying decision interval. Results from the calculation demonstrated that planned management could conserve precisely fifty percent of the lighting's power price value with no probable loss of lettuce yield (Albright, 2008).

The University of Arizona's Controlled Environment Agriculture Center (UA-CEAC) uses LED modules accompanied by blue and red channels in each growing shelf at remotely and independently controlled light intensity. Traditionally designed and constructed data accession and graphical user interface enables the constant checking of the intensity of light in the surrounding air, electrical conductivity, carbon dioxide, air temperature, pH levels, relative humidity and the oxygen produced from the nutrient solution. It also allows checking of resource use like energy, water and carbon dioxide with carbon dioxide injection control at the same time (UAg Farm - Vertical Farming, n.d.).

1.3 Statement of the Problem

Light has three different aspects of their significant influence on plant growth, namely, intensity, the spectrum and duration. These aspects under the plant's natural condition collects light from sunlight, and dependent from this, the plant does not fully receive the favorable aspects it needs to greatly increase the efficiency of plant growth. Indoor planting has been alternatively used as a controlled environment to monitor the behavior and dependency of plants from an independent light source, from which the main problem is how to produce the considerable optimization and control of the three different aspects of light that the plant needs in order to maintain its proper growth regulation. As an independent light source, many researchers used LED as an alternative source. The LED lighting system needs to be controlled in every stage of the plant to efficiently provide the necessary light requirement for optimal plant growth and development.

1.4 Objective of the Study

GENERAL OBJECTIVE:

To design and develop a growth dependent LED Lighting System through Image Processing using ANFIS Algorithm.

SPECIFIC OBJECTIVES:

1. To construct a chamber and plant bed for lettuce plants with controlled environment.
2. To design a lighting system as an alternative light source.
3. To design a vision system that will determine the stage of the plant growth.
4. To develop an algorithm that will control the lighting system
5. To test the developed system through actual cultivation of plants.

1.5 Significance of the Study

In a recent study, it states that light serves as two key roles for plants (Pocock T. , 2016). First, it provides energy for growth of the plant. Second, it provides information that elicits the plants' response including plant shape and nutritional content. Although light is a requirement for the growth of the plant, excess light absorbed can be damaging. At the same time, insufficient light causes negative effects for the plant.

The development and implementation of this study will automate the cultivation of plants that will result in more efficient energy consumption and improved plant characteristics. This will also help the farmer's over-all productivity in terms of labor and quality of the plant. This study will provide the necessary framework and system that can be used as a reference for future studies regarding horticulture and smart agriculture technology.

1.6 Scope and Limitations of the Study

The scope of this study is solely based on the implementation of lighting control and the temperature control system as a reliable source of lighting to promote growth and development of edible plants. A vision system will be implemented using a mounted camera and image processing using Python. The vision system will determine the current growth stage of the plant and will serve as the input for the LED Lighting System. The intensity, the spectrum and duration of the light will be controlled and monitored using Raspberry Pi and Arduino Microcontroller. The system will use Fuzzy Logic Algorithm accompanied by the implementation of the Artificial Neural Network to manage the lighting that will be programmed using the Python programming language. Serial communication will be used as the medium between controllers for transmitting and receiving data. This study only focuses on the lighting based on the stage of the plant and its period of planting. It does not include the other factors that can affect the growth of the plant, especially oxygen, water, and mineral nutrients.

CHAPTER 2
REVIEW OF RELATED LITERATURE

2.1 Conceptual Literature

2.1.1 Controlled Environment Agriculture

Controlled environment agriculture is the way towards developing plants within a developed room like greenhouse and enables the farmer to keep up the correct amount of temperature, light radiation, humidity, carbon dioxide, H2O, nutrients and levels of pH for the production of crops. It also reduces the rates of parasites or sickness, increases general effectiveness and spares reserves (Controlled Environment Agriculture (CEA), n.d.).

2.1.1.1 Indoor Farming

Indoor farming is an alternative method of cultivating crops indoors. It applies growing methods like hydroponics and uses artificial lights for providing nutrients and required light levels for plant growth (Indoor Farming, n.d.)

2.1.1.2 Lettuce (Lactuca sativa)

The lettuce was grown below different light situations, for example, the day/night sequence, light intensity and the proportion of dark period. The light condition and light energy requirements has an effect on the quality of lettuce. Lettuce is light sensitive. When seedlings emerged two or three days later than the main crop, their growth will be delayed because of the competitive effects of the bigger crops (Lettuce, n.d.).

2.1.1.3 Temperature

Temperature also affects the growth of lettuce. The germination temperature of the crop requires 40 to 85 °F. The best germination for the crop is below 70 °F since the seeds can go dormant at high temperatures (Growing Guide - Lettuce, n.d.).

2.1.2 Light

Plants utilizes light radiation as a wellspring of data and vitality, it uses light as an origin of data and as an asset by means of photosynthesis. Light serves two critical roles for plant growth and development. First, it provides energy for growth of the plant. Second, it provides information that elicits the plant's response including plant shape and nutritional content (Pocock T. , 2015).

2.1.2.1. Light Emitting Diode (LED)

The LED is an electronic device which discharges perceptible light if a flow of electricity passes across it. The LED has been portrayed as having a moderately narrow-band spectral range of light and has an exceptional potential when it comes to crop production. It contains extended working lifetime, little area, wavelength explicitness, good sturdiness and other advantages that are ideal in plant lighting design (Carney, Venetucci, & Gesick, 2016).

Light Emitting diodes can be on different colors which are significant in the intensity needed by the plant. In different studies show that red and blue lights are essential for green vegetables. Red light can stimulate photosynthesis and indicate wavelengths of 600 to 700 nanometers that are efficient in absorbing plant pigments (Hristozkova, Geneva, Stancheva, & Velikova, 2017).

2.1.2.2 Lighting Conditions

Table 2.1 Plant info table for lettuce.

Growth Stage	Seedling	Vegetative	Harvesting
Light ($\mu mol/m^2/s$)	80	150	200
Duration (days)	14	14	7

In this study, only one plant will be used namely, Lettuce (Lactuca sativa). Figure 2.1 shows the ideal light intensity and duration for Lettuce plants. These are critical recommendations for lighting to positively affect plant enlargement and improvement. Using these guidelines, lighting profiles can be created and adjusted to attain maximum efficiency and the desired plant characteristic (Langhans & Tibbitts, 1997).

2.1.2.3 Photosynthetically Active Radiation (PAR)

The PAR measures the light accessible to activate photosynthesis, that is located in the 400 to 700 nanometer wavelength spectral range of light and measured as mmol of light energy per m^2. It is necessary for the photosynthesis and plant growth and changes seasonally depends upon the scope and hour of the day. At night, PAR becomes zero. Typically, amount of PAR covers about 0 to 3,000 mmol/m^2, and often reach 2,000 to 3,000 mmol/m^2. Observing PAR is imperative to guarantee crops are accepting the amount of light needed for the procedure (Staff, 2010).

2.1.3 Color Space

2.1.3.1 RGB

RGB color space, also known as the RGB color system is color space that uses the combination of primary colors red, green and blue to represent all colors. Digitally, each primary color has 8 bits which makes 256 integer values from 0 to 255, thus making 16777216 possible colors from combinations of primary colors. RGB color space is commonly displayed in LED monitors by combining blue, red and green LEDs in every picture elements (RGB Color Codes Chart, n.d.).

2.1.3.2 HOG

Histogram of Oriented Gradients is a feature descriptor for object detection and commonly used in computer vision and image processing. The method of the descriptor counts the alignment of the gradient occurred within the limited portion of an image identification window or area of concern (Histogram of Oriented Gradients (HOG) Descriptor, 2018).

2.1.3.3 HSV

HSV color wheel, sometimes represented as a cone or cylinder, is a color space based on how human vision perceives color. Hue represents the portion of the model that depicts color and expressed in number starting with the value of 0 up to 360 degrees. Saturation constitutes to the gray value present from the hue, expressed in the value of 0 to 100%. Radiance or value constitutes the hue intensity and works in conjunction with saturation expressed from 0 to 100 percent (Understanding the HSV Color Model, 2018).

2.1.4 Algorithm

2.1.4.1 Fuzzy Logic

Fuzzy Logic within a limited sense is an intelligent framework that is related to a multivalued logic. Fuzzy logic is an application of the fuzzy sets or uncertain sets. In a deeper meaning, it follows the theory of sets that has elements with degree of membership or classes of objects with degree of membership (What Is Fuzzy Logic? - MATLAB & Simulink, n.d.).

It is necessary to extend systems of fuzzy logic with multiple hedges. Fuzzy logic aims at modelling logical reasoning with vague or unspecific statements which contains linguistic hedges (Le, Liu, & Tran, 2009).

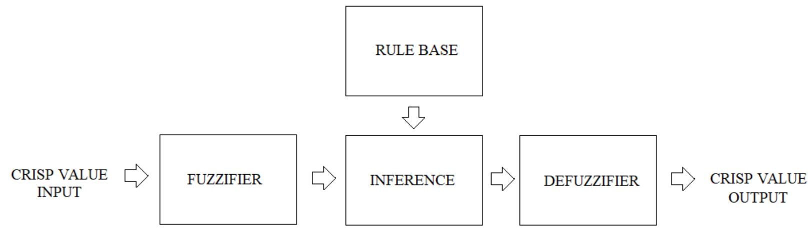


Figure 2.1 Fuzzy Logic Block Diagram

Figure 2.1 shows the block diagram of the fuzzy inference system. In the first section, the fuzzifier converts crisp values or precise values into fuzzy value then the degree of membership is determined. This data then goes to the Inference section where the inference process takes place. This associates membership functions together with the rule base to make a decision or a "fuzzy output". This data then goes to the defuzzifier where defuzzification takes place. This is the process of deriving an output based on the given input or fuzzy sets, the rule base and degrees of membership function. The lighting system was designed in order to save energy and satisfy lighting comfort using fuzzy logic. The system was able to regulate the lighting efficiently resulting to an effective controller in saving energy (Liu J. , Zhang, Chu, & Liu, 2016).

2.1.4.2 Artificial Neural Network

Artificial Neural Network or ANN is clearly like a human brain; it is developed system for processing information. It is used for processing complex and nonlinear information, and is able to work in layers and recognize complex patterns and relationships as it learns. ANN is modeled on the design of human brain. Through learning, the structure of the neural network changes until such time it can find and recognize the patterns (Suparta & Alhasa, 2016).

2.1.4.3 Adaptive Neuro-fuzzy Inference System

The Adaptive Neuro-Fuzzy Inference System, or ANFIS, is neuro-fuzzy system that combines the methods of artificial neural network (ANN) and fuzzy logic. It uses the capability of fuzzy logic to process abstract information and qualitative traits of human thinking. However, in fuzzy logic, each membership function and rule bases is tuner manually. The learning capabilities of the ANN can be used for adjusting the Membership Functions and setting the rule base. Thus, ANFIS is more capable when compared to standard fuzzy logic. Through ANFIS, the rate of errors are greatly reduced (Suparta & Alhasa, 2016).

2.2 Related Literature

2.2.1 Lighting System for Controlled Environment Agriculture

The growth rate of crop increases by enhancing the effect of light to the plant using artificial light as an alternative to sunlight. Although agricultural lighting is not a new study, it has a better efficiency over the traditional farming for the sustenance of light for photosynthesis. The LED lighting system of agricultural lighting efficiently increases crop yields as it enables more energy-efficient feature than light in traditional farming (LED application in agricultural lighting can efficiently increase crop yields, 2017).

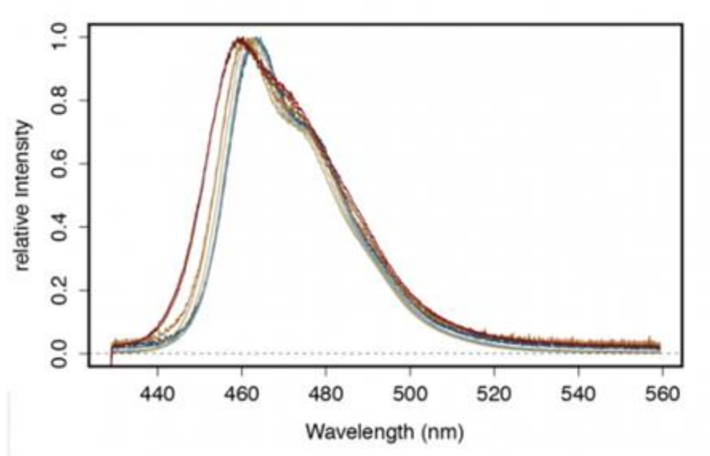


Figure 2.2 LED Spectrum

(Retrieved from https://www.arrow.com/en/research-and-events/articles/agriculture-lighting)

Figure 2.2 shows that the output of a single-wavelength LED at different drive currents, there is a shift in the emission wavelength because of the temperature changes in the LED. With an integrating sphere, the spectra recorded was a 50 µm fiber with a 25 µm slit and an 1800 lines/mm holographic grating.

The required resolution for measurement was reduced through a relative spectrum of LEDs that would allow the use of ultra-compact spectrometer, such as STS-VIS that has a resolution of 1.5 nm (Light Source Characterization in Life Sciences, 2016).

The objectives in optimization of genetic algorithm were applied for the lighting system design where fixed parameter is used. The result shows that there is a drastic decrease in the number of LED lamps used. Hence, it reduces the investment and operating cost while it maintains the required light integral capacity and uniformity. Thus, controlled agricultural practices with an optimized environment results to better production of plants with better quality even in unusual seasons and locations (Santiago, Jose, Bandala, & Dadios, 2017).

Table 2.2 Summary Table for Lighting System for Controlled Environment Agriculture

Title	Objective	Approach	Advantage	Disadvantage
LED Lighting in Controlled Environment Agriculture	To orient that LEDs must be applied commercially and to learn of its benefits to utilities and agriculture	Investigation of three primary questions regarding to the comparison of LED and high pressure sodium (HPS) lighting in controlled environment	The study shows the reliability of LED over the usage of 6,000 hours	The study is still under questions regarding to the new technology and validations of unproven claims of LED manufacturers
Productivity, absorbed Photosynthetically active radiation, and light use efficiency in crops: Implications for remote sensing of crop primary production	To determine the temporal behaviors in long term and short-term constitutive variations in the component produced from soybean and maize which is LUEgreen	Establishment in the relationship of the illumination consumed by vegetation to the canopy GPP and LUE measurement through numerous years' analyzations on irrigated and rain-fed maize and soybean plants with distinctive canopy construction, physiology and leaf composition.	The day-to-day observation carefully monitors the progress of the study	The long-term period of observation consumes more time before obtaining the result
Controlled Environment Agriculture (CEA) LED Lighting Systems. New Metrics	To evaluate potential metrics for utilization in the CEA	Application of numerous objective modifications of genetic calculation for the lighting framework design using fixed parameters which includes modification factors, bits amount for each variable and greatest amount of repetitions	The LED sources provides higher energy efficiency and variable spectral components essential for plant needs	The capability of real-time control are not integrated by existing greenhouse lighting systems

2.2.2 Characteristics of Lettuce in Light

A study focuses on the effects of various spectral wavebands on the growth and development of lettuce. The light treatment is the new method used by turning of specific wavebands results to changes of the accumulation of biomass, morphologic characters, gas exchange in photosynthesis, chlorophyll and soluble sugar contents of different growth stages of lettuce. The results also show that plants grown under LG treatment have distinct reduction of fresh weight and moisture content. LY and LP obtained higher fresh shoot weight and moisture content while A/Ci in LG significantly reduced by 33.3% and 36.1%. At lower PPF, green light has coupling effects with other wavelengths for improvement of lettuce growth, and is closely related to its fraction in wide spectrum. While irradiation of green light wavelength affects photosynthetic pigments in lettuce more than irradiation of yellow and purple light, yellow light “knock out” increases soluble sugar content and purple light showed the opposite trend. The results showed the great effect of green, yellow and purple light to biomass, photosynthesis and soluble sugar content of lettuce dependent on its growth period (Liu, Fu, Hu, Yu, & Liu, 2018).

Another study shows that high pressure sodium (HPS) lamps are not the most efficient light source for plant production despite of being an excellent light source. The study also shows that specific wavelengths under 400 nm to 700 nm affects photosynthesis directly more than other wavelengths. The advantage of LED light systems reduces the lighting cost and energy consumption by only using the specific wavelengths necessary for plants resulting to maximum plant production and efficient energy consumption. The results of the experiment show that at three light intensities (high: 135 mmol-mL2-sL1, medium: 115 mmol-mL2-sL1, and low: 100 mmol-mL2-sL1) at three red (661 nm) to blue (449 nm) ratio levels (5:1, 10:1, and 19:1), excluding fruit production, the highest biomass occurred at 19:1 red-to-blue ratio while the higher fruit production occurred at 5:1 red-to-blue ratio. Increasing light intensity also results to increasing growth. The 50:50 ratio shows the highest fruit production followed by 5:1 and 19:1 ratio, both at high light intensities. The 5:1 ratio performed consistently (Deram, Lefsru, & Orsat, 2014).

Another study explores the effects of supplemental qualities of light to the nutrition and growth aspect of lettuce. The crops were cultured through hydroponics for 35 days, mixed light qualities of white and other supplemental light such as blue (B), green (G), yellow (Y), red (R) and far-red (Fr) provided by light-emitting diodes (LEDs) were used. In light control, the white LED was used together with photosynthetic photon flux (PPF) value of 135 μmol m/s^2, basal white light in each treatment was 105 μmol m/s^2, and the PPF of supplemental LED was approximately 30 μmol m/s^2. It shows that supplemental lights made distinct morphological changes to the crops. WR results are more compact and vigorous yield. WY and WFr results are scant and twisted yield. WB results are dwarfed plants with larger leaves. With the comparison to the plants under control light, the fresh shoot weights of crops increased up to 63.2% and 21.7% under supplemental R and B while supplemental Fr decreased fresh shoot weights by 35.9%. Supplemental R and B give higher chlorophyll and carotenoid contents, Supplemental B and G results to nitrate content was lessening, supplemental G shows significant soluble sugar accumulation, and supplemental Fr Increases S/R ratio and accumulation of ascorbic acid and gives lower biomass and pigment content. Supplemental Y does not have any positive effect on the specimen (Chen, Xue, Guo, Wang, & Qiao, 2016).

Table 2.3 Summary Table for Characteristics of Lettuce in Light

Title	Objective	Approach	Advantage	Disadvantage
Supplemental lighting orientation and Red-to-Blue ratio of light-emitting diode for greenhouse tomato production	To directly influence photosynthesis greater than different wavelengths particularly in spectral ranges of blue and red beams.	A greenhouse with a center computer that controls the water system, ventilating system and lighting system and a combination of a misting structure for removing heat	Performance of an arrangement of illumination trials using a scope of distinctive light-assessing technologies for finding the best suitable for measurements of LED point source arrangements	Typical spectroradiometers and light-assessing technologies made for measuring light quantities in either sunlight or different origins of light with light dispersion toward each path that are not compatible to LED arrays
Effect of green, yellow and purple radiation on biomass, photosynthesis, morphology and soluble sugar content of leafy lettuce via spectral wavebands "knock out"	To study the effects of various ranges of wavelengths to leaf lettuce enlargement and improvement	Control of individual narrow waveband of LEDs with same types assembled in the same column	Unique advantages of several LED lighting systems which includes the determination of spectral configuration, smaller area, higher photosynthetic proficiency, longer life expectancy, less heat diffusion and higher safety performance	Uneven distribution of irradiation

Table 2.4 Continuation of Summary Table 2.3

Title	Objective	Approach	Advantage	Disadvantage
Growth and nutritional properties of lettuce affected by mixed irradiation of white and supplemental light provided by light emitting diode	To expand the monetary productivity of plants yield and nourishment capability of vegetables through precise management of the luminescence and spectral wavebands in contained surroundings.	Performance of lighting considerations utilizing intensity-alterable LED boards with purposefully planned and gathered displacement in the middle of the LED boards and the crop's canopy	Narrower bandwidth, lower heat output, longer lifespan, lower mass or size and conserves more energy than conventional origins of light that is used for cultivation	Demonstration of green light that is not as efficient as red and blue radiation for activating biomass collection of lettuce sprouts because of its restriction of piercing rate
Characterization of Indoor Light Conditions by Light Source Classification	To encompass light vitality gathering structures	Experimental evaluation for various regular lightings inside a closed environment below various situations	Various outcomes show that the strategy used can recognize light sources accompanied by a top categorization validity	The technique was utilized precisely in circumstances with restricted intervention

2.2.3 Characterization of Light

Characterization of light is important for determining the available energy levels in ambient light energy harvesting systems. The light conditions in indoor was described by its illuminance levels and are observed that solar panels produce different output powers based on spectral response even with identical illuminance.

The study distinguishes the conditions through a method based on limited spectral information. It shows that the same method with very high accuracy in classification that can be used to determine the light sources and can also be used accurately in situations with limited interference which makes cheaper alternative using spectrometers in the characterization of light conditions (Ma, Bader, & Oelmann, 2017).

In a certain wavelength region, it is required to have absolute irradiance measurements for a good characterization of light source with the aid of spectrometer to perform the task. Integrating sphere can effectively use for measuring LED's emission and cosine corrector, at the point of use, ideally measures the illumination from the light source at a certain distance (Light Source Characterization in Life Sciences, 2016).

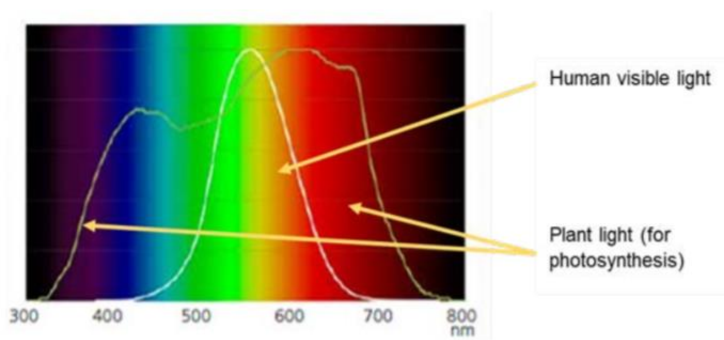


Figure 2.3 Rate of Light Absorption for Plants Versus Humans

(Retrieved from https://oceanoptics.com/light-source-characterization-in-life-sciences/)

Figure 2.3 shows the comparison between the plants and humans light wavelengths, measured in nanometers. The y-axis shows the initiation of photosynthesis response in plants due to light absorption rate. There are three things to consider the photosynthetic rate of a plant in getting the relative quantum efficiency: 1) CO_2 uptake, 2) the light energy at different wavelengths and 3) light absorption (Carney, Venetucci, & Gesick, 2016)

Table 2.5 Summary Table for Characterization of Light.

Title	Objective	Technique/Approach	Advantage	Disadvantage
Fuzzy logic controller for energy savings in a smart LED lighting system considering lighting comfort and daylight	To operate lighting condition in the best vitality-conserving condition.	Inference method	Robustness and relatively simple design becomes the advantage of controllers as it doesn't need to have full learning of the definite framework	Contentment in lighting is a personalized assessment of the fulfillment of users of the value within the closed environment and has troublesome ranking precision with definite limits

2.2.4 Different Algorithms used for Lighting Systems

A study about an optimal design for greenhouse crop production was developed using genetic algorithm (GA). The same algorithm uses evolutionary parallel search capabilities for designing the layout of light source, which include mounting heights and power requirements. It offers a high degree of freedom since the total number of light source and their exact positions are not predefined. The study develops a fitness function for the algorithm that considers uniformity of light, capability of light intensity and other parameters. The designed system showed the improvement of the uniformity of supplemental lighting systems under the optimization process of GA and offers substantial savings without affecting the light intensity capabilities of the system. The position of the light sources at the finalized system designed by GA follows the pattern of having more light sources at the edge and less at the middle of the growing area (Ferentinos & Albright, 2004).

Another study is about an intelligent lighting system with fuzzy logic controller that uses white LED as a source of optimal and efficient light requirement for a typical room space. The system has automatic control for window shades of rooms that harvest daylight. The results showed the reduction of LED output average power as the amount of daylight that enters the room increases. The system shows its intelligent optimization of the high efficacy LED and natural daylight for the required levels of illuminating the room. The results also demonstrated the use of fuzzy logic for processing an outdoor light level signal for automatic control of the window shade position of a typical room, and harvesting daylight for maximum energy efficiency for illumination. The study also shows the process of light intensity level sensor signal through fuzzy logic controller and its use for intelligent control of light intensity and duration. However, the lowest level of the lighting system is not equal to zero because of the limitation of the fuzzy logic controller of having an output approximately equal to zero (Mutua & Mbuthia, 2015).

Another study is about the goal of artificial lighting systems of ensuring appropriate illumination with high energy efficiency. The system incorporates daylight control but its behavior is influenced by other factors particularly the position of sensors. Illuminance on the work-plane is more likely not correlated with illuminance measured by photo-sensors to control the light sources that leads to incorrect information of daylight control system which affects its efficacy. An application of artificial neural network (ANN) is needed for providing a method of obtaining the relationship between the illuminance on the work-plane and the measured illuminance by photo-sensors. ANN can process complex data set for providing output that gives illuminance in a point. Using the measured values in an experimental setup, the output of ANN related to different sensor placements is analyzed, making it possible to find the best position of the photo-sensor that accurately determines the work-plane illuminance with a mean square error of 2.20E-3 and R2 of 0.9583. The experimentation of the same method showed R2 from 0.9101 to 0.9246 thus proving the capability of ANN to achieve the main goal of artificial lighting systems (Beccali, Bonomolo, Ciulla, & Brano, 2018).

Another study explores the self-adaptive weighted data fusion algorithm. The study develops an android app via handheld devices for controlling smart LED lighting system. The handheld device displays readings of the status of the energy usage and treated as a basis for the system lighting mode design. Equipment such as a multimeter, wireless light dimmer and IR learning module are connected via RS 232/285 and GUI on touch screen. The study also developed a wireless data communication designed for operation in compliance with ZigBee standard. Signal processing was made through self-adaptive weighted data fusion algorithm for sending date. Experimentation demonstrates low variation in data fusion with high stability. The wireless light dimmer and IR learning remote module were directly instructed by command from human computer interface, and the multimeter reading are displayed via server. The smart LED lighting system that can control the color and intensity of light implements cost savings and solves the light-flashing problem, which is an issue for vision health. The luminosity is precisely controlled to obtain the light requirement of the user at specified place and time (Sung & Lin, 2013).

A study focuses on Newton algorithm applied in energy-saving control strategy for lighting system with multiple light sources. A new method under this algorithm was developed to lessen the consumption of light energy by separately manipulating the luminosity of multiple light sources, and the control of proportion-differentiation-integration was used to obtain appropriate lighting level (Yin, et al., 2017).

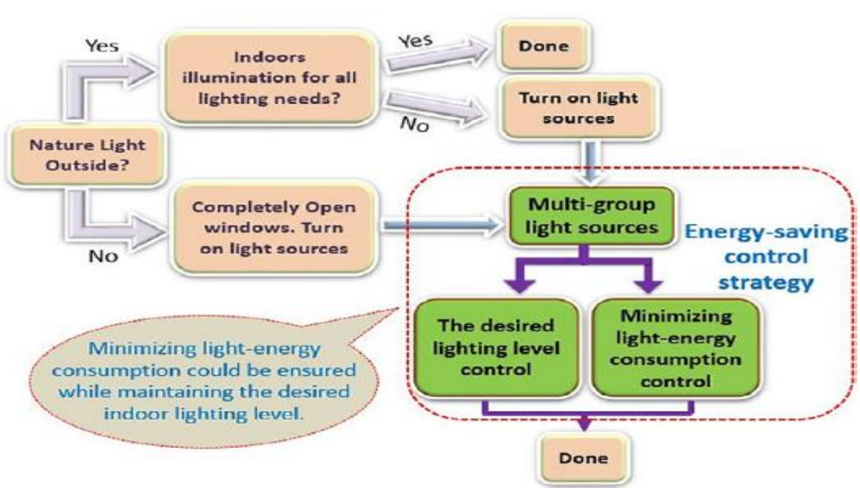


Figure 2.4 Energy Saving Control (Yin, et al., 2017).

The brightness of multiple light sources is manipulated to obtain the desired lighting level and the adjustment has an effect on the consumption of light energy. Thus, an energy-saving control strategy is necessary to decrease the consumption of light energy while maintaining the desired lighting level. The results showed improvement on the accuracy of tracking algorithm using the proposed controller and helps the system to obtain the minimum consumption of energy faster (Yin, et al., 2017).

Since the lighting consumes large proportion of energy, a fuzzy based controller that considers daylight, movement information and lighting comfort to achieve energy savings was developed. DALI protocol was used for communication of the controller and LED luminaires. The results of the simulation show that the wider controllability of lighting system provides to operate lighting environment at most energy-saving state. The results also show that the use of the designed controller minimizes significant energy consumption while maintaining light comfort (Liu t. , Zhang, Chu, & Liu, 2015).

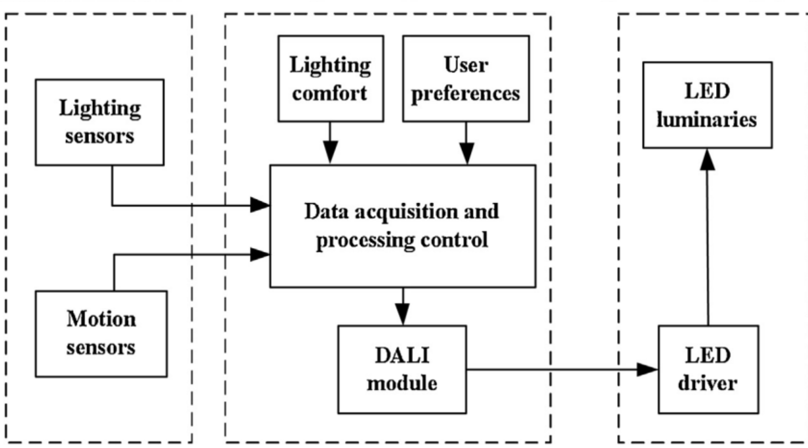


Figure 2.5 LED Control (Liu t. , Zhang, Chu, & Liu, 2015)

A decision-making unit that considers daylight and the users' movement in the environment was developed for processing information and providing dimming was used to regulate the LED drivers in the artificial lighting output. The main objective is achieving the energy savings under the requirements of lighting comfort. However, there is a difficulty of defining lighting comfort precisely. Fuzzy logic is necessary to solve the low precision. A group of artificial lighting illumination requirement follows the designed lighting output. This control strategy maintains the illumination level on the table at a constant level. The data shows the illumination levels on the tables are consistent despite of continuous change in the amount of daylight. Significant energy can be saved based on various lighting preferences (Liu t. , Zhang, Chu, & Liu, 2015)

A study about the horticulture of lettuce focuses on the utilization of red blue light-emitting diode as its light source in Simple Nutrient Addition Program (SNAP) hydroponics setup. The experiment compared the two setups which are the conventional SNAP hydroponics and SNAP hydroponics with LED light source. The evaluated results of the experiment showed the significant effect of LED light source on the number of leaves and leaf area of a lettuce, giving more capability for a lettuce to grow more and larger leaves in a controlled environment. Furthermore, the weight of the lettuce under the SNAP with LED light source setup was 30 percent greater than the one under conventional hydroponics setup (Amado, Valenzuela, & Orillo, 2016)

Table 2.6 Summary Table for Different Algorithms used for Lighting Systems.

Title	Objective	Approach	Advantage	Disadvantage
Assessment of indoor illuminance and study on best photo sensors' position for design and commissioning of Daylight Linked Control Systems. A new method based on Artificial Neural Networks	To maintain the suitable brightness level with strong vitality proficiency based on the main outline implementation and specialized principles	Analysis of production of numerous artificial neural networks identified with various sensor positions using the measured values in experimental setup	The brightness level on work level surface is almost always related to the measured brightness level on the image-sensing device utilized for luminaire regulation, which prompts incorrect data for sunlight-connected regulating system influencing its effectiveness	Strong influences of several factors, sensor positions in particular, to the behavior of the system
Design and Implementation of a Smart LED Lighting System Using a Self-Adaptive Weighted Data Fusion Algorithm	To develop a small LED lighting framework that is regulated in a distant location by applications from an Android phone	Remote controlled smart LED lighting system with self-realization method empowered using a phone by means of a Wi-Fi transference	The condition of vitality usage is shown from the phone, managed as a basis for the method of lighting that is outlined on the framework	No alternative devices can be used for displaying the output of sensors when the handheld device breaks
Energy-saving control strategy for lighting system based on multivariate extremum seeking with Newton algorithm	To improve the efficiency of light energy and reduce the consumption of electric energy	Development of an up to date multiple variable, min/max value searching regulating technique using Newton calculation for minimum light-energy consumption and proportion-integration-differentiation control approach for obtaining the desired lighting level	Increasing the merging rate of the closed loop framework for least consumption of light vitality and improvement of the exactness of the regulating procedure	MISO-ESCNA and PID are complicated methods used in the study

Table 2.7 Continuation Summary Table 2.6

Title	Objective	Technique/Approach	Advantage	Disadvantage
Exterior lighting computer-automated design based on multi-criteria parallel evolutionary algorithm: optimized designs for illumination quality and energy efficiency	To solve the problem of multi-objective optimization	Presentation of conceptual basis of this study: standards taken into account; metrics for comparison of various lighting designs; point-to-point method for calculation of illuminance on a meshed working plane; semi-mechanized lumen procedure for ordinary territories, with fundamentals of genetic calculations and further exploration of corresponding variation with acquired multiple target system	Specialized software aids the system in very desirable manner is considered as requirement for dealing with lighting designs	The current accessible business programming projects doesn't contain artificial intelligence procedures which left engineers to find feasible solution
Fuzzy logic controller for energy savings in a smart LED lighting system considering lighting comfort and daylight	To communicate the controller with LED luminaires To operate light conditions with the best vitality conserving condition.	Consideration of sunlight, variation data with lighting contentment to fuzzy logic controller design	Achievement of installed lighting system to energy reserve funds with satisfaction of client's contentment in the lighting with consideration of daylight contribution	The changing in the position of the client within the workplace are not taken into account

Table 2.8 Continuation Summary Table 2.7

Title	Objective	Technique/Approach	Advantage	Disadvantage
Intelligent Lighting System Design With Fuzzy Logic Controller	To create light on the needed brightness amount within a regular room area.	Simulation of the design using Fuzzy Logic Toolbox and Simulink blocks in MATLAB software environment	Intelligent optimization of planned lighting framework from the top adequacy LEDs with regular sunlight within the illumination of a room to needed extents	Fuzzy logic is a tool that deals in proportion to the indeterminate and irregularity problems required for forming a selection
Exterior lighting computer-automated design based on multi-criteria parallel evolutionary algorithm: optimized designs for illumination quality and energy efficiency	To plan the outline arrangement of the lanterns, their staging elevation and their amount of power.	Developmental corresponding seeking potentiality of genetic calculations	The large degree of freedom of genetic algorithm system for planning procedures	The limitation of possibilities of staging elevations and power amount of the lanterns to four unique quantities for each lantern in this investigation
Horticulture of Lettuce (Lactuca sativa l.) Using Red and Blue LED with Pulse Lighting Treatment and Temperature Control in SNAP Hydroponics Setup	To devise a method to manipulate temperature and red-blue LED light source for the SNAP hydroponics setup of the horticulture of lettuce.	Comparison of conventional SNAP hydroponics and SNAP hydroponics with LED light source	The automation of the control system focuses on other factors that affects the plant like temperature.	The lighting system is controlled under the programmed schedule.

CHAPTER 3

METHODOLOGY

3.1 Conceptual Framework

INPUT

KNOWLEDGE REQUIREMENT

- Lettuce Light Requirements
- Photosynthetically Active Radiation
- Python Programming
- Image Processing
- ANFIS Algorithm

HARDWARE REQUIREMENT:

- Raspberry Pi
- Arduino Mega
- Adafruit NeoPixel Digital RGB LED Strip
- DC Power Supply
- Camera
- PAR Sensor

SOFTWARE REQUIREMENT:

- Python

PROCESS

HARDWARE DEVELOPMENT

- Plant Chamber
- Vision System
- LED Lighting System

SOFTWARE DEVELOPMENT:

- Feature Extraction
- ANFIS Algorithm
- LED Control

TESTING:

- Growth Rate and Quality

OUTPUT

Lighting System dependent on plant stage and light requirement

Figure 3.1 Conceptual Framework

Figure 3.1 shows the conceptual framework of the study. The figure shows the main sections of the study that is composed of INPUT – PROCESS – OUTPUT. This study focuses mainly on providing the light requirement for every stage of the plant, this requires knowledge on the light requirement of the plant the the Photosynthetically Active Radiation emmited by the LED Lighting System. A vision system will be developed and will be used to gather data from the plants. That data will be the input for the ANFIS algorithm wherein it will output the plant stage and light requirement. A Raspberry Pi 3 Computer will be used as the main processing unit of the system while an arduino will be used as the controller for the Lighting System

3.2 Research Process Flow

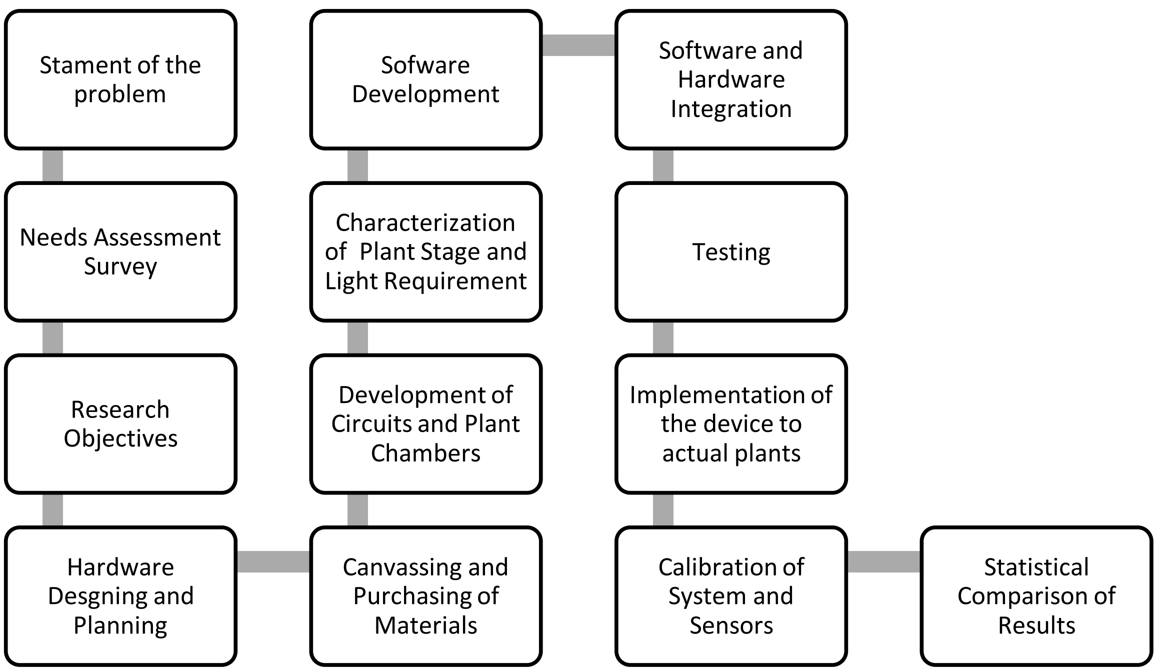


Figure 3.2 Research Process Flow Diagram

Figure 3.2 shows the process flow of the research. It is to be followed for the completion of the objectives.

3.3 Hardware Design

This section represents the tangible part of the proposed research study. It is composed of the design of the plant chamber, circuit diagrams of the lighting and temperature control of the system.

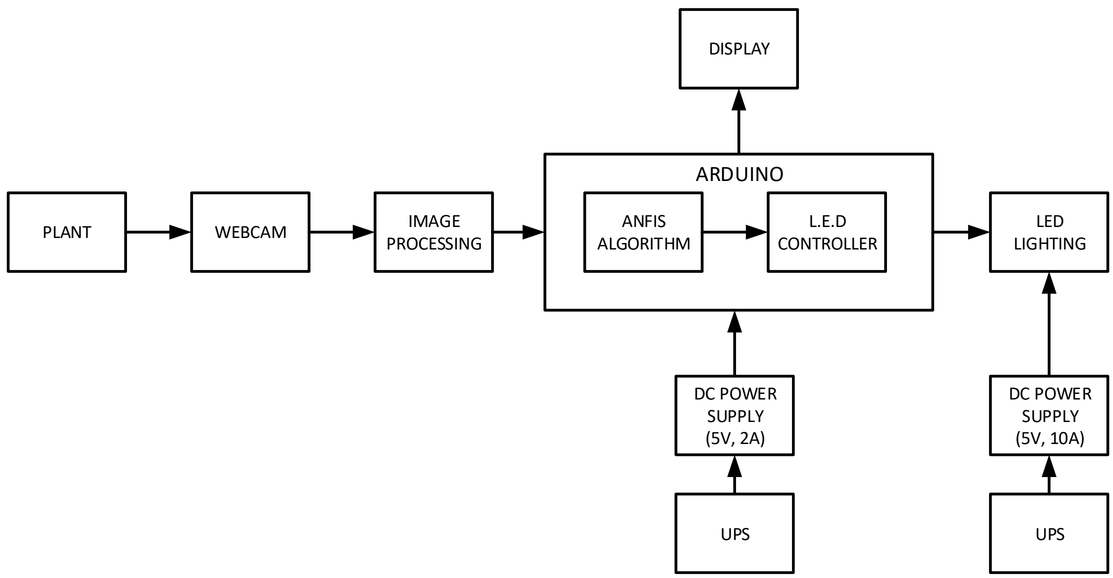


Figure 3.3 Project Flow Diagram

3.3.1 Design Considerations

The proposed system will be implemented in an enclosed chamber wherein the light and temperature parameters are monitored and controlled. Temperature sensors will be implemented for constant monitoring. A cooling system composed of a Microcontroller, inlet fan and exhaust fan will be used for maintaining the desired temperature of the chamber. RGB NeoPixel LED will serve as the artificial light source for the plants. Cameras will be used for the Vision of the system.

3.3.2 Circuit Diagram

The figure shown below is composed of Raspberry Pi 3, Arduino Microcontroller, USB Hubs, RGB NeoPixel LED strips, protective circuits and DC Power Supply. The Raspberry Pi 3 serves as the Main Control Unit, it contains the program for the Image Processing, Database and Algorithm for decision making. The Arduino Microcontroller will serve as the main controller of the LED light. It will be connected to the Raspberry Pi where it will receive information and make the appropriate adjustments to the light to satisfy the light requirement of the plant. A DC power supply with high current rating will be used as the main source of power for the lighting system, as separate DC power supply will be used for the Raspberry Pi while the Arduino Microcontroller will draw power from the Raspberry Pi. All power supplies will be connected to a UPS as backup power supply in case of power interruptions.

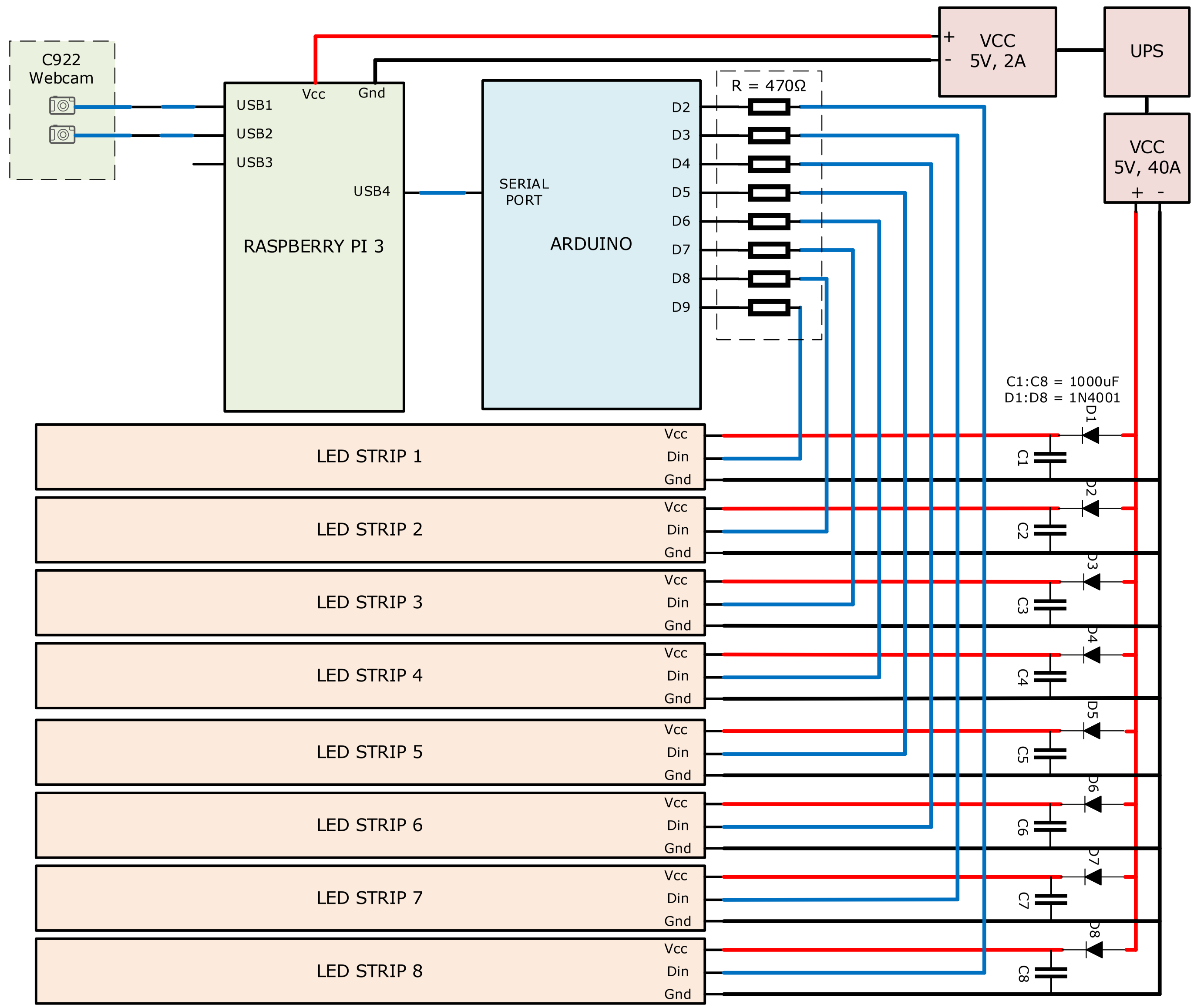


Figure 3.4 Schematic Diagram

3.3.3 Project Components

The primary project components used for the project are the Camera, Raspberry Pi, Arduino Microcontroller, Adafruit NeoPixels LED Strip, SD card, Monitor, Air Conditioner, Blower Fans and Temperature Sensors.

3.3.3.1 Vision System

A Logitech C920 Webcam will be used as hardware for the Vision System. It will be installed directly above the plant bed in all chambers and will be interfaced through a Raspberry Pi 3 Computer. The Logitech camera was chosen due to its high definition image capturing capabilities (1080p,30fps,720p and 60fps)

Figure 3.5 Logitech C922 Webcam
(Retrieved from https://www.logitech.com/en-us/product/c922-pro-stream-webcam)

3.3.3.2 Temperature Control

The project uses air conditioner to maintain the desired temperature in every stage of the plant. Temperature has a major role in the growth of the plants.

Figure 3.6 AC Unit

(Retrieved from https://www.abenson.com/wconz006ec.html)

3.3.3.3 Artificial Lighting

Adafruit NeoPixel Digital RGB LED Strip will be installed in parallel above the plant bed and will serve as artificial lighting. An Arduino Microcontroller will be used for the control of the light quality, intensity and duration of the Lighting System. Adafruit NeoPixels LED strip uses 5V working voltage. LED strip is chosen because of its less heat dissipation and long-time-span of usage.

Figure 3.7 Adafruit NeoPixel RGB LED
(Retrieved from https://www.makerlab-electronics.com/product/adafruit-neopixel-digital-rgb-led-strip-black)

3.3.3.4 Lighting Controller

An Arduino Microcontroller will be used as the controller for the Lighting System since multiple LED Strips will be independently controlled.

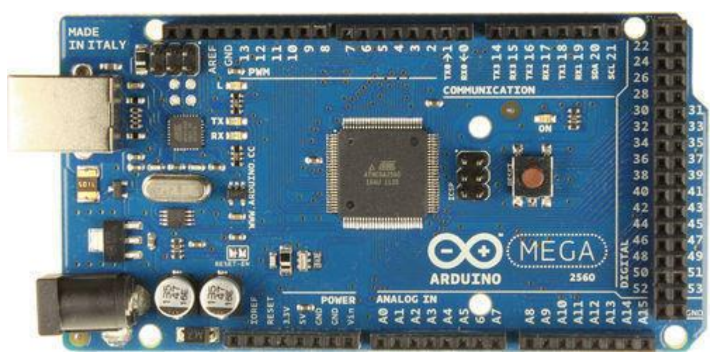


Figure 3.8 Arduino Microcontroller
(Retrieved from https://store.arduino.cc/usa/mega-2560-r3)

3.3.3.5 Computer

A Raspberry Pi 3 computer will be used for the project. It will be used as the platform for high level programming such as Image Processing and Algorithms. Local Databases can also be easily created. The Vision System and the Lighting Controller will be interfaced with the Raspberry Pi.

Figure 3.9 Raspberry Pi 3

(Retrieved from https://www.raspberrypi.org/products/raspberry-pi-3-model-b/)

3.4 Plant setup

Figure 3.10 and 3.11 shows the plant cultivation setup for both conventional and controlled lighting setups. Each plant is labeled A, B, C and D for the conventional setup while each plant in the controlled lighting is name E, F, G and H. Each plant for both setups has a spacing of 30 inches in between plants.

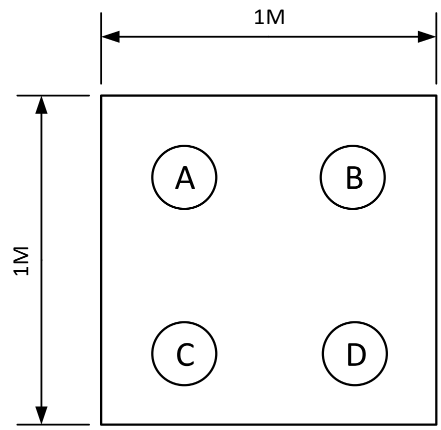


Figure 3.10 Plant cultivation setup for conventional setup.

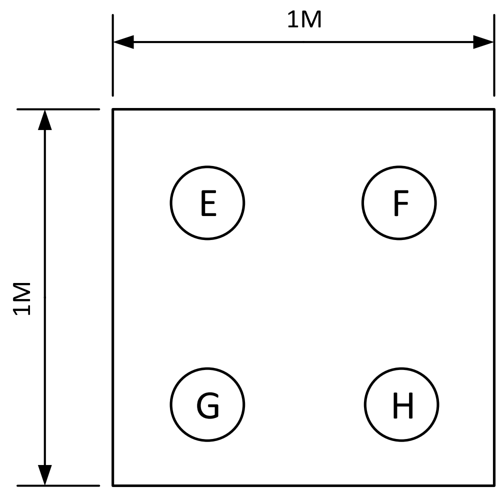


Figure 3.11 Plant cultivation setup for controlled lighting setup.

3.4 Software Development

3.4.1 Programming Platform and Language

Python will be used for the programming of the Vision System and Algorithm due to its high-level capabilities. It is easy to use, powerful, and versatile, making it a great choice for programming. OpenCV which has support for Python will be implemented for programming the Vision System. It is designed as a specific library of programming functions aimed at real-time computer vision. The Raspberry Pi 3 will be the platform on which the program will be written on. The Arduino Microcontroller will be the platform for the lighting control and will be programmed using the Arduino IDE

3.4.2 Vision

The Vision software of the system will be programmed using Python and interfaced through Raspberry Pi 3. A C922 camera will be used for the Image Acquisition. This will be used for extracting the features of the plant to and will be the input for the Algorithm.

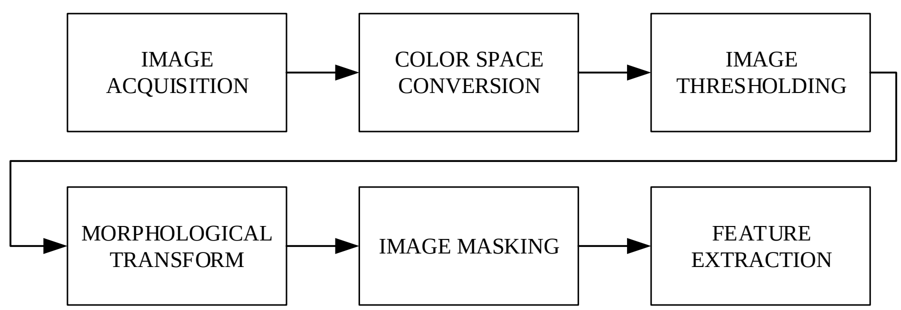


Figure 3.12 Block Diagram

Figure 3.12 shows the block diagram for the vision system. It starts with an image being captured by the camera. That image will undergo image processing wherein the captured RGB image will be converted to L*a*b Color space. The a-value will be extracted then will undergo binary thresholding filtering out the background of the image. After thresholding, it will undergo Morphological Processes including Erosion and Dilation wherein the noise of the image will be filtered out. The filtered binary image will then be masked with the RGB Image then will undergo feature extractions where the RGB, HSV and HoG parameters are extracted.

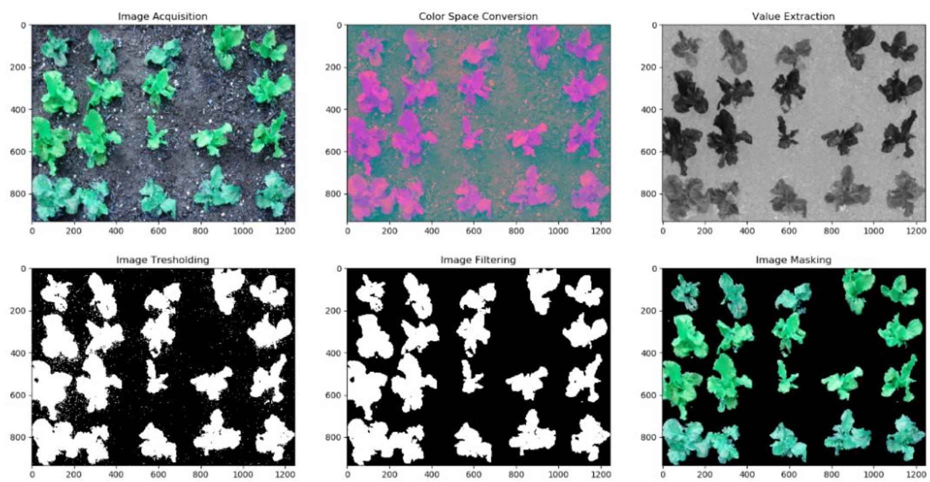


Figure 3.13 Feature Extraction Process

Figure 3.13 shows the actual process that the image undergoes from Image Acquisition to Image Masking. The masked image will be undergoing feature extraction where in the RGB, HSV and HOG of the image will be extracted then sent to the Algorithm for determining the growth stage.

3.4.3 Adaptive Neuro-Fuzzy Inference System

Objective knowledge like mathematical models or equations are used in solving engineering problem. Subjective knowledge which represents linguistic information usually impossible to quantify using traditional mathematics. Both types of knowledge are required to solve real world problems. A combination of Fuzzy Logic System and Artificial Neural Network called Adaptive Neuro-

Fuzzy Inference System will be implemented for this project. It was chosen because it incorporates the learning abilities of ANN and excellent knowledge representation and inference capabilities of fuzzy logic. It has the ability to self-modify their membership function to achieve a desired performance resulting to be more precise in terms of efficiency.

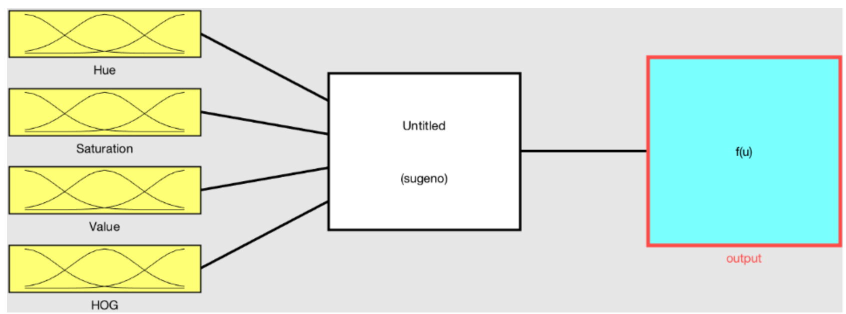


Figure 3.14 Fuzzy Inference System

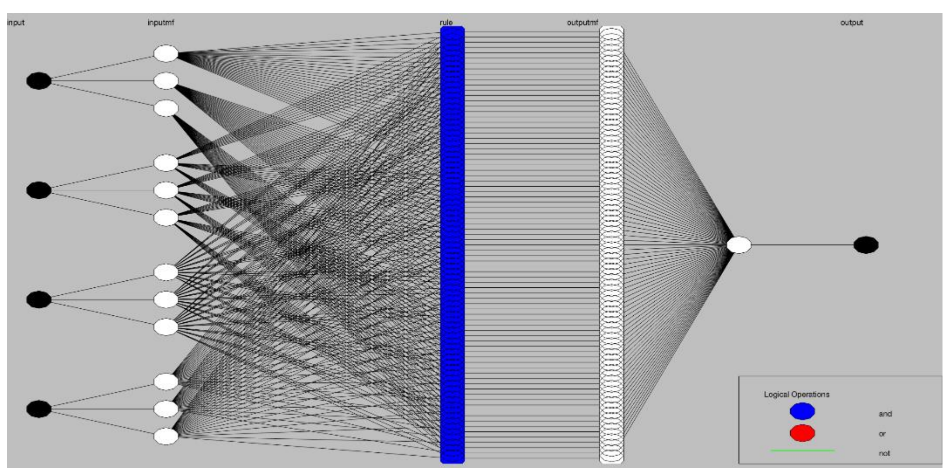


Figure 3.15 ANFIS Network design.

Figure 3.14 shows the Fuzzy Inference System to be modeled. The system will compose of 4 inputs which are Hue, Saturation, Value and Histogram of Gradient. The system will determine the light output based on the rules that will be set by the Neural Network. Figure 3.15 shows the ANFIS Network design. It shows the ANFIS structure for the system to be modeled.

3.4.4 Flowchart

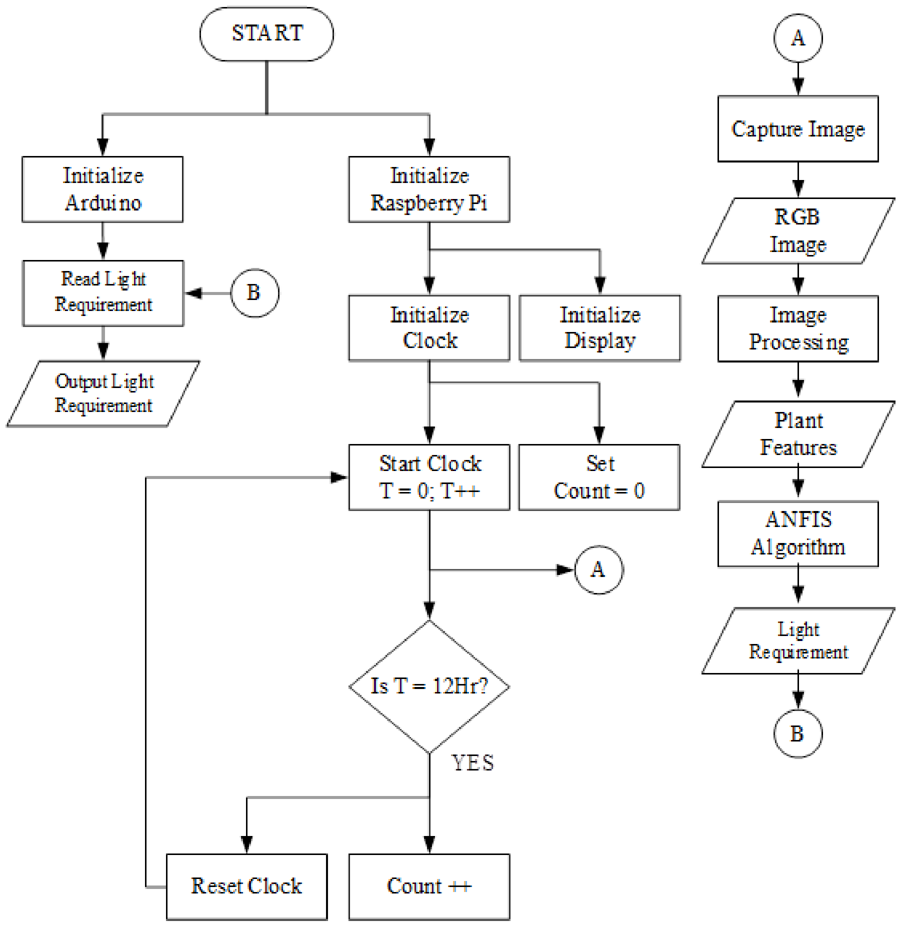


Figure 3.16 Program Flowchart

Figure 3.16 shows the Program Flowchart. The program starts off with the initialization of Sensors, Controllers and Microcontrollers. The main program starts with the Raspberry Pi where the Clock will start. After 12hrs, the Vision system will trigger where it will perform Image Processing (A) then the clock will reset to 0. After processing the image, it will go through the ANFIS Algorithm (B) where the stage will be determined. That information will be sent to the Arduino Microcontroller where it will trigger the Lighting Control Program (C). A separate system will be running on the background where the temperature of the chamber is monitored and controlled automatically.

3.5 Evaluation Procedure

Measuring crop growth is a crucial part in determining the quality of the plant that is shown on each of its growth stages. From the first stage to the last stage, it shows all the basis for data analysis which takes time accumulation for the whole procedure to perform. These different features on each growth period can be utilized to surely describe and assess crop yield and development that are based upon soil properties, weather conditions and crop diversities

Every plant stages the number of leaves of each lettuce were recorded. To measure the leaf area index, the diameter of lettuce must be obtained using a Digital Vernier Caliper. The canopy area is then obtained by using the measured diameter to compute for the area of the circle. Then, the leaf area is obtained from each plant using the Petiole app on a smartphone, which automatically shows its value when captured. The leaf surface area of each leaf is added and was divided by the calculated canopy area of the plant.

The plant's fresh weight was also measured by first removing the plant from the soil and then washing off any loose soil. The next procedure was blotting the plants with a soft paper towel to remove any free surface moisture. Afterwards, each plant was weighed immediately on a weighing scale because they dry up quickly and may result inaccurate data.

The lighting that was being illuminated on the crops was measured using a PAR sensor and was connected via laptop on a software called Logger Lite that shows the graph and values of the measured light spectrum. The temperature inside the isolated chamber were also measured using a thermometer attached on the wall inside the chamber. Other measurements include plant height which were also measured by the digital Vernier caliper.

3.6 Gantt Chart

Table 3.1 Gantt Chart

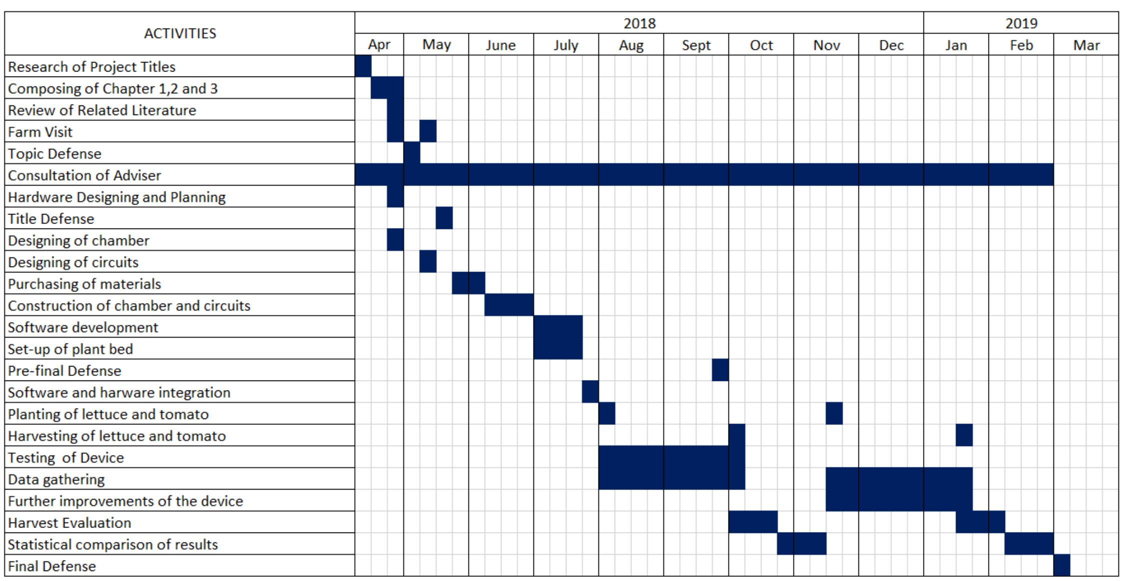


Table 3.1 shows the Gantt chart which is a graphical representation of the proposed project schedule. It shows the proposed plans and task to be completed from start to finish of the project

CHAPTER 4
RESULTS AND DISCUSSION

This chapter presents the technical description, capabilities and limitations of the project. Evaluation, tabulation of results and interpretation of the gathered data is also included in this chapter.

4.1 Project Technical Description

This project is about developing a growth dependent LED lighting system that uses image processing and Adaptive Neuro-Fuzzy Inference System algorithm in order to deliver the optimum required light requirement for the specific stage of the lettuce plants resulting to better quality and faster growth rate. The setup of the lighting controller is installed inside a controlled environment chamber with automated irrigation.

The design of the project includes Adafruit Neopixel RGB LED strips as alternative light source capable of delivering a wide spectrum of color. Logitech C922 Pro Webcam capable of capturing high definition images, Raspberry Pi B and Arduino Mega as controller for the entire system, Real-Time Clock module to provide real time scheduling, +5V 10A DC Power Supplies, air-conditioning unit and traditional horticulture setup.

4.2 Project Structural Organization

Figure 4.1 shows the main lighting system, DC power supply and AC unit of the designed chamber. The DC power supply is responsible of providing the necessary power requirements of the lighting system and the main controller. The AC unit is responsible for maintaining the required temperature for optimal growth. Lastly, the main lighting system is responsible for producing the output of the ANFIS algorithm.

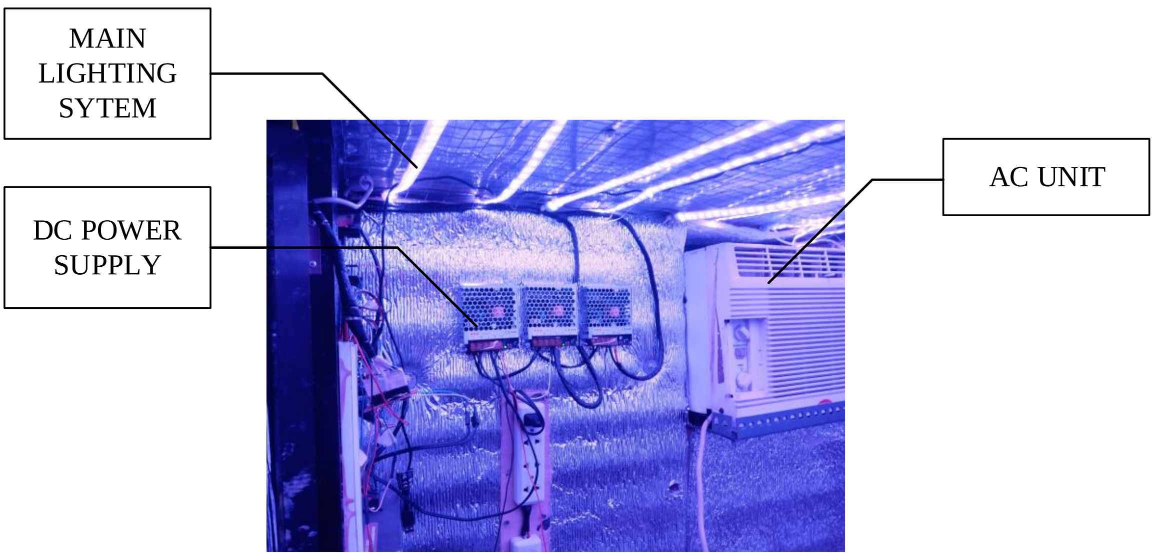


Figure 4.1 Main lighting system, AC Unit and DC Power Supply

Figure 4.2 shows the side lighting system which serves as additional lighting to produce a higher PPFD. The irrigation system is responsible for automatic irrigation for the plant bed. The plant bed designed is able to house 4 lettuces simultaneously.

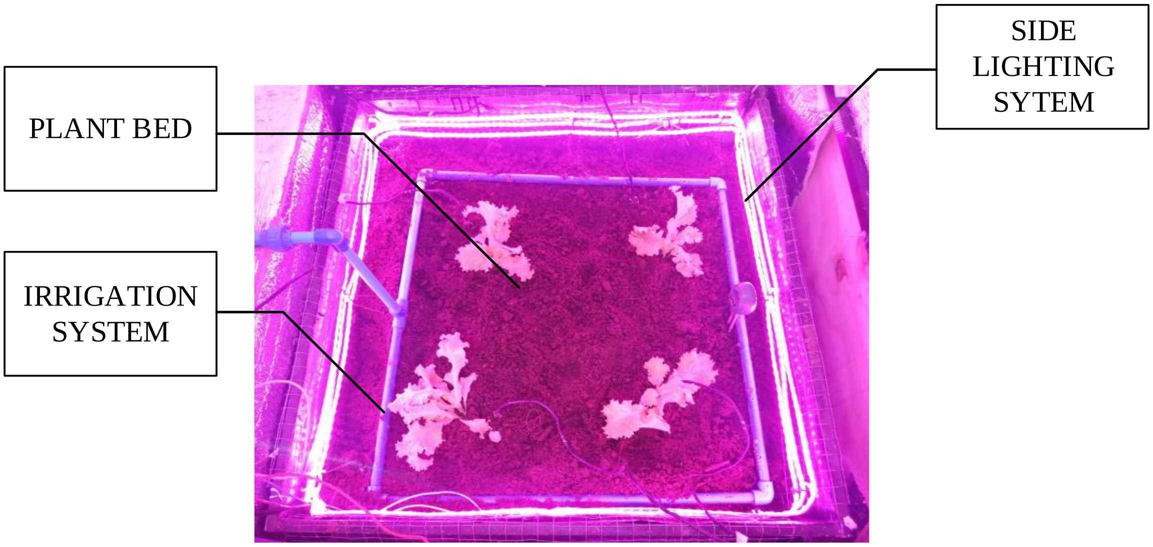


Figure 4.2 Plant bed, side lighting system, irrigation system

Figure 4.3 shows the main controller panel. It serves as the brain of the system. It is responsible for the automated capturing of the plant bed, real time scheduling, lighting system control, data logging and processing of data.

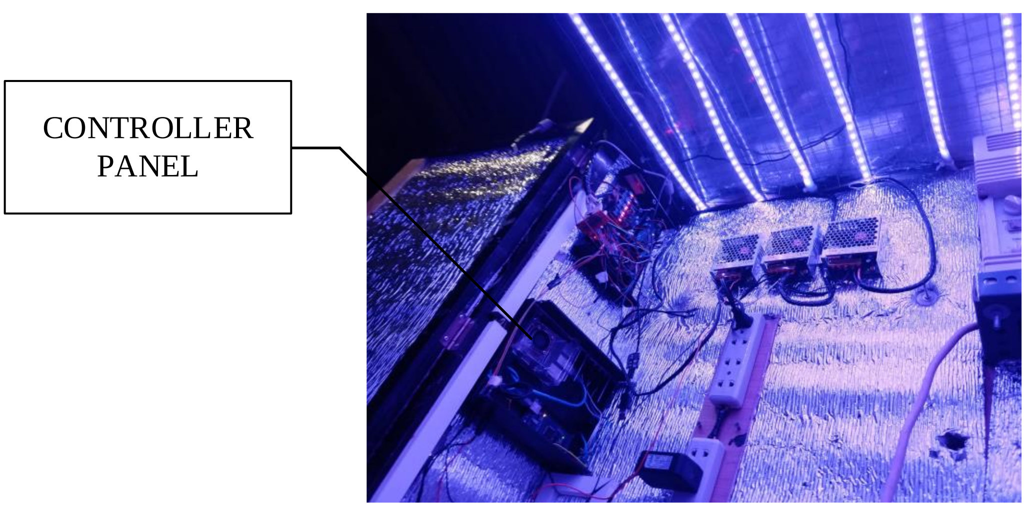


Figure 4.3 Main controller

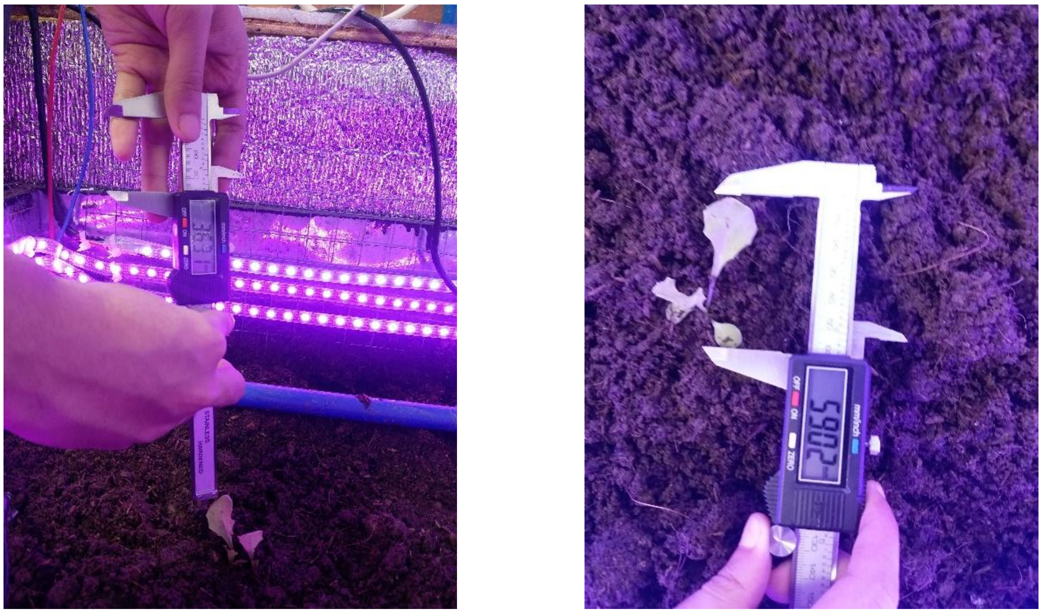
4.3 Project Capabilities and Limitations

The system is designed to be fully automatic. The image capturing of the plants is scheduled with the help of a Real-Time Clock module. Subsequently, feature extraction will take place where it will extract the necessary image features from the captured image automatically. The system is capable of accurately predicting the light requirement based on the stage of the plant through the developed ANFIS algorithm. The RGB light source used is able to produce the light given by the algorithm within the required PPFD range. Also, a local database is implemented for data logging and easy monitoring. Overall the system is capable of delivering the required light requirement for the lettuce plant. However, the system is only limited to a specific type of lettuce namely Grand Rapid Lettuce. Due to the limited space in the designed chamber, the algorithm and script is designed to process only 4 samples of lettuce plants. Lastly, the algorithm is trained in a very specific setup. Any alterations to the setup like changing the angle or height of the camera, changing the light intensity when capturing, and increasing the number of lettuce plants inside the chamber will greatly affect the results of the algorithm and will produce inaccurate information. Also, the study is focused entirely on the lighting of the chamber. The effects of other environmental conditions including temperature, humidity and irrigation is not included in this study.

4.4 Project Evaluation

Numerous programs checking and accuracy testing were performed for the assurance of the correctness of the project's results. This were considered for the proper implementation of each installed equipment of the Lighting Control System. The settlement of the crop comprises of an appropriate housing with a wooden chamber with a metallic foundation fit for industrial applications. The proponents considered to install numerous LED strips surrounding the plants area including from above the canopy and around the ground area occupying all available space from the ceiling and on the walls of the plant bed. This is to supply the right amount of lighting and to provide the needed PAR measurement sensed by the PAR sensor for its approved consistency. In addition, for high quality of its cultivation, the proponents also deliberated the use of loam soil with added vermicomposting to further improve the richness and fertility of the soil increasing its growth and yields. This is tested according to the right amount of its pH value needed for the specific type of crop. The indoor settlement includes an air-conditioned room for the temperature control to provide the cool environment adaptive for the nature of the crop. The system provides an HD camera for improved image quality necessary for the distinguishable characteristics obtained during image processing of every crop. The proponents considered to provide a scheduled image-capturing of the plants coupled with everyday monitoring and caring of the crops, consistently, up to the day of its harvest. This is to ensure the stable condition of the proper growth and yield of the crops during data gathering. Finally, for evaluating the crop. The height and diameter is measured using a Vernier caliper for accurate measurements and the number of leaves are counted.

Figure 4.4 shows the crop evaluation procedure. The height is measured using the depth tool of the digital Vernier caliper. The longest diameter of the crop is taken as the diameter of the plant.



a b

Figure 4.4. a.) Height Measurement; b.) Diameter Measurement.

4.4 Tabulation of Results and Interpretation

4.4.1 Feature Selection

Table 4.1 presents the summary of the results of the statistical analysis. The R-Squared values are obtained by using linear regression for each individual axes of the color space and comparing them to the cultivating period of the lettuce plant. Based on the results, the color space YCbCr and Pixel Count are correlated with cultivation period of the plant. As such, those components are used as inputs in the ANFIS algorithm.

Table 4.1 Regression analysis summary table

COMPONENT	R^2
R	0.123
G	0.001
B	0.142
H	0.047
S	0.333
V	0.001
L*	0.004
a*	0.505
b*	0.263
Y	**0.913**
Cb	**0.811**
Cr	**0.834**
Pixel Count	**0.935**

4.4.2 ANFIS Algorithm

Table 4.2 shows the data obtained by training different FIS functions. Based on the results, gauss2mf shows lowest linear error rate. As such, gaus2mf was chosen to be the membership function for training the ANFIS algorithm.

Table 4.2 Training Data for different FIS Functions

FIS Functions	Constant error rate	Linear error rate
trimf	0.018082	0.012814
trapmf	0.017051	0.010471
gbellmf	0.01109	0.010538
gaussmf	0.011596	0.009531
gauss2mf	0.012373	**0.008976**
pimf	0.012236	0.009651
dsigmf	0.012323	0.0090923
psigmf	0.012323	0.090865

Table 4.3 presents the ANFIS information for the gauss2mf Membership Function. The ANFIS was trained using 648 lines of data obtained from data gathering and was tested using 72 data pairs. Based on the results, the trained model yields a 0.92% error rate.

Table 4.3 ANFIS information for the gauss2mf

Item	**Value**
Training RMSE	0.0092
No. of nodes	193
No. of linear parameters	405
No. of nonlinear parameters	48
Total no. of parameters	453
No. of training data pairs	648
No. of checking data pairs	72
No. of fuzzy rules	81
Optimization tool	hybrid

Figure 4.5 and 4.6 shows the Photosynthetic Photon Flux Density or PPFD (umol/m^2/s) measurement for every plant at 5-day increment. Figure 4.3 shows the PPFD measurement on the conventional setup where the plant uses sunlight as source for photosynthesis. The graph shows that the PPFD obtained from sunlight is random. This is due to varying weather conditions. Figure 4.4 shows the PPFD measurement on the controlled lighting setup. Based on the graph, the PPFD emitted by the lighting system is consistent with a downward trend throughout the growth period of the plant. Due to the design of the lighting system, the plant receives consistent lighting throughout its growth period.

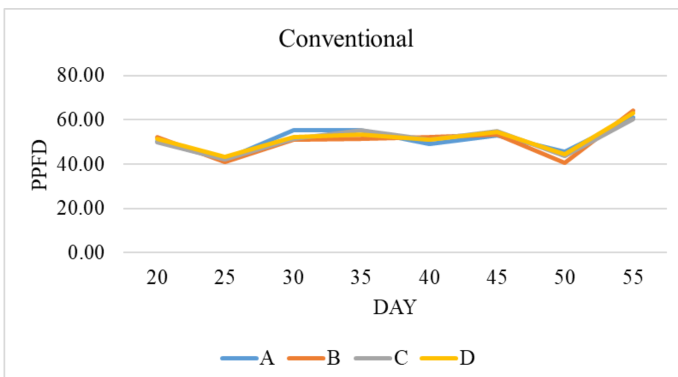


Figure 4.5 PPFD measurement on conventional setup.

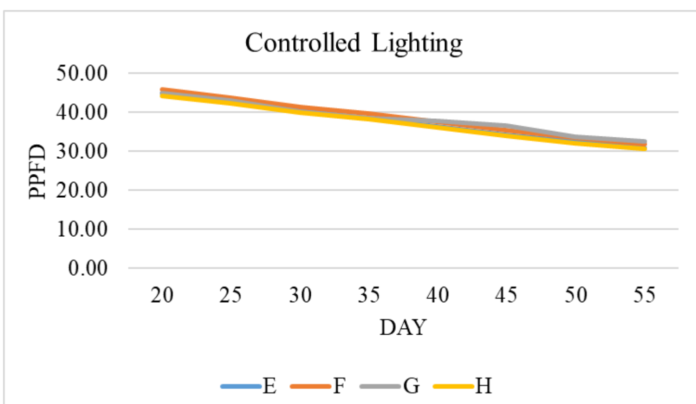


Figure 4.6 PPFD Measurement on controlled lighting setup.

4.4.4 Plant Parameters

Figure 4.7 show the time series plot all plants in the conventional and controlled lighting setup. As shown in the graph, 3 out of 4 plants in the conventional setup attained a relatively low height when compared to the controlled lighting setup.

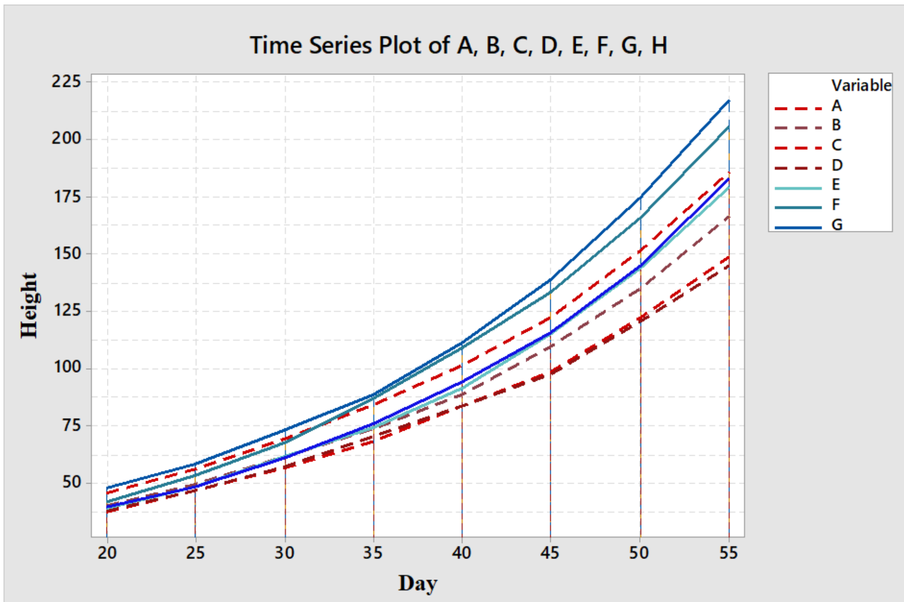


Figure 4.7 Height Time Series Plot

Table 4.4 shows the summary table for the average percent difference of the height of each plant taken every 5 days. As shown in the table, the conventional setup yields an average of 21.59% difference while the controlled lighting achieved an average of 24.56%. Comparing the two results shows that the controlled lighting setup is 13.76% higher compared to the conventional setup.

Table 4.4 Summary Table for height difference (%)

Conventional		Controlled Lighting	
Plant	Difference	Plant	Difference
A	21.9	D	24.36
B	20.4	E	25.4
C	22.2	F	24.2
D	22	G	24.3
Average	21.59		24.56

Table 4.5 shows the summary table for the results of regression analysis. Each growth rate of both setup is obtained and was compared. Using T-test, a p-value of 0.00036 was obtained. Thus proving that there is a significant difference between the conventional setup and controlled lighting setup.

Table 4.5 Summary Table for height growth rate

Conventional		Controlled Lighting	
Plant	Growth Rate	Plant	Growth Rate
A	0.1947	D	0.2164
B	0.1886	E	0.2261
C	0.1996	F	0.2167
D	0.1977	G	0.2176

Figure 4.8 shows the canopy area times series plot for both conventional and controlled lighting setups. Based on the graph, the plants cultivated in the controlled lighting setup attained a higher canopy area when compared to the conventional setup.

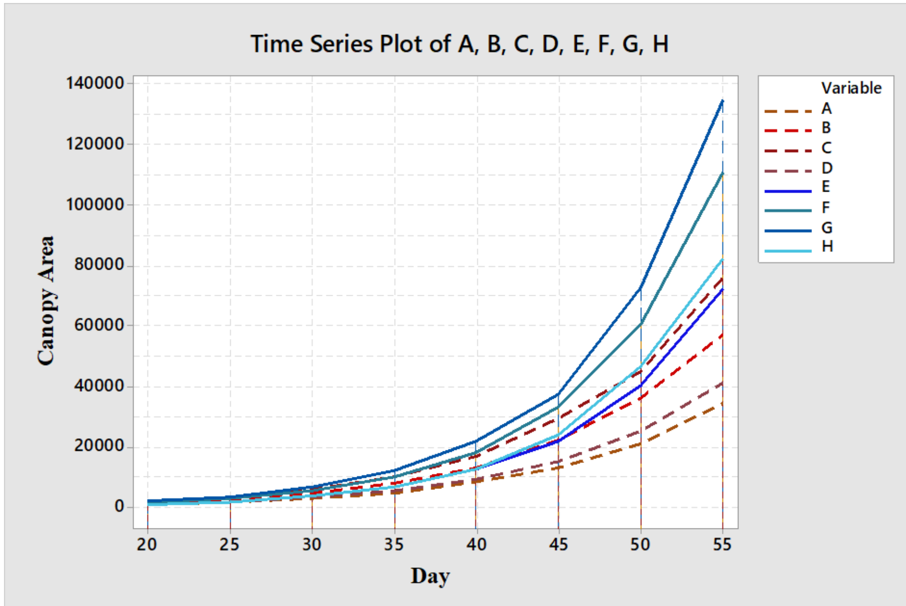


Figure 4.8 Canopy Area Time Series Plot

Table 4.6 shows that the conventional setup has an average of 27.87% while the controlled lighting averaged at 34.68% growth in terms of canopy area. Computing for the percent increase shows that the controlled lighting is 24.43% higher compared to the conventional setup.

Table 4.6 Summary table for canopy area difference (%)

Conventional		Controlled Lighting	
Plant	Difference	Plant	Difference
A	21.9	D	24.36
B	20.4	E	25.4
C	22.2	F	24.2
D	22	G	24.3
Average	21.59		24.56

Table 4.7 presents the summary table for the canopy growth rate. Results from statistical analysis yield a p-value of 7.9E-6. This shows that the lettuce grown in the controlled lighting produced a significant difference when compared to the conventional setup in terms of growth rate.

Table 4.7 Summary table for canopy area growth rate

Conventional		Controlled Lighting	
Plant	Growth Rate	Plant	Growth Rate
A	0.4964	D	0.5927
B	0.5085	E	0.5926
C	0.5079	F	0.5909
D	0.5046	G	0.6161

Figure 4.9 shows the time series plot of the number of leaves for both conventional and controlled lighting setups. The graph shows that all the plants grown in the controlled lighting yield a higher number of leaves.

Figure 4.9 Number of leaves Time Series Plot

Table 4.8 shows the summary table for the growth rate of leaves. Using T-test with an alpha of 0.05 and hypothesized mean difference of zero yield a p-value of 0.00189. This shows that the growth rate of leaves in the controlled lighting is significantly higher when compared to conventional setup.

Table 4.8 Summary table for leaves growth rate

Conventional		Controlled Lighting	
Plant	Growth Rate	Plant	Growth Rate
A	0.1607	D	0.1942
B	0.1654	E	0.1977
C	0.1775	F	0.2093
D	0.1787	G	0.1978

Table 4.9 shows the result of the T-test statistical analysis. An alpha value was set at 0.05 and the hypothesized mean difference was set at 0. The null hypothesis dictates that there is no statistical difference between the conventional setup and controlled lighting setup in terms of height, number of leaves and diameter. After conducting a t-test, a p-value less than the alpha was obtained for the three parameters. This shows that the null hypothesis is rejected.

Table 4.9 Summary of statistical analysis results

Variable	P-value two tailed test
No. of leaves	0.00189
Height	0.00036
Diameter	0.0000079

Table 4.10 shows the summary of the results of Principal Component Analysis. It shows the coefficients of the principal components of the controlled lighting setup. In order to interpret each component, the magnitude and direction of the coefficients is examined. Greater magnitude of the coefficient indicates that the variable has a greater impact in explaining the variation. The sign tells the direction of the variable; a negative sign indicates an inverse relationship while the absolute value indicates the strength of the relationship. Comparing the results, the lighting has a higher magnitude compared to soil moisture. This shows that the lighting will have greater impact compared to soil moisture. The negative sign indicates that there is an inverse relationship between the lighting and growth. This is also proven by examining the results of the measured values. As the plant grows, the produced PPFD of the lighting system decreases.

Table 4.10 Summary of Principal Component Analysis

Variable	Principal Component 1
Lighting	-0.426
Soil Moisture Before Watering	-0.129
Soil Moisture After Watering	0.018

CHAPTER 5

SUMMARY OF FINDINGS, CONCLUSIONS, AND RECOMMENDATIONS

This chapter presents the summary of findings based on results on the series of tests and experiments done on the duration of the study.

5.1 Summary of findings

The developed system utilizes image processing to extract image features. The system was able to extract different 12 color space axes and the pixel count of the image. Based on statistics, the color space YCbCr shows an R-squared value of 0.9133, 0.8106 and 0.8342 while the pixel count resulted to an R-squared value of 0.9347 which is the highest value attained among all the other components. The features pixel counts and Y, Cb, and Cr components, based on the statistical analysis, have shown that they are directly correlated with the cultivation period. During the early stages of the crop, the lighting system was producing a PPFD of 44.47 µmol/m^2/s. As the crop grows, it was observed that the PPFD produced was decreasing. At the harvest stage, the lighting system produced a PPFD of 31.39 µmol/m^2/s. Upon comparing the height of the plants grown in the chamber with plants grown outside using the conventional method. It was observed that there was a 11.59% difference in height. Comparing the canopy area of lettuce grown in the controlled lighting and conventional setup yield a 21.4% difference. After completing a whole cycle of the lettuce growth, the number of leaves of the lettuce grown in the chamber shown an increase of 14.83%. Furthermore, comparing the growth rate of the height, canopy area and number of leaves of the controlled lighting and conventional setup yield a statistically significant difference.

5.2 Conclusions

Based on the results of the study and the findings, the following conclusions are derived:

1. Comparing the data between the controlled lighting setup and the conventional setup has shown that the lettuce plants grown in the controlled lighting produced better crops in terms of height, canopy area and number of leaves. The designed chamber effectively presents the advantage of the controlled environment over conventional farming.
2. Results show that lettuce grown with controlled lighting produced a significant increase in terms of height, canopy area and number of leaves. The lighting system effectively produced the right quality, quantity and duration of the light for better plant growth.
3. Based on statistical analysis, Y, Cb, Cr and Pixel count have shown direct correlation with plant growth. The vision system precisely extracts the required features that is statistically related to the growth stage of the plant
4. The modeled algorithm yield a 0.92% error. Based on results the algorithm correctly produces the required output of the lighting system based on the determined growth stage of the plant.
5. The developed system has successfully cultivated lettuce plants with an 11.59% increase in height, a 21.4% increase in canopy area and shown an increase of 14.83% in the total number of leaves.

In conclusion, the systems developed by the proponents was able to produce the expected results with great accuracy. Therefore, the design and development of a growth dependent LED Lighting System through Image Processing using ANFIS algorithm is successful.

5.3 Recommendations

The following are the recommendations that could be implemented for further improvement of the study.

1. Redesign plant chamber or consider vertical farming with hydroponics setup.
2. Create a new algorithm that will identify plant growth that is independent to camera height, angle and lighting.
3. Create a new system that can detect and provide the suitable lighting conditions for any plants.

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APPENDIX A

ADDITIONAL TABLES

Table 1. Summary of feature selection data

DAY	Pixel Count	R	G	B	H	S	V	L	A	B	Y	Cb	Cr
20	1193	187.89	197.42	181.93	0.28	0.09	0.77	78.30	-6.05	6.71	17.07	127.97	127.98
20	1180	188.67	196.41	182.49	0.28	0.08	0.77	78.17	-5.17	6.13	17.06	127.97	127.98
20	1170	184.32	192.34	177.95	0.27	0.08	0.75	76.63	-5.38	6.35	17.02	127.97	127.98
25	3190	180.25	194.07	165.31	0.24	0.15	0.76	76.55	-9.89	12.90	18.72	127.82	127.93
25	2927	167.38	176.93	152.41	0.23	0.14	0.69	70.66	-7.78	11.45	18.31	127.85	127.96
25	2968	178.41	191.90	163.68	0.25	0.15	0.75	75.75	-9.70	12.71	18.51	127.84	127.94
30	5259	181.60	196.17	167.23	0.25	0.15	0.77	77.25	-10.19	12.90	20.55	127.71	127.88
30	5049	187.16	200.26	173.50	0.25	0.14	0.79	78.91	-9.26	11.92	20.56	127.73	127.89
30	5195	190.17	201.02	174.33	0.24	0.14	0.79	79.35	-8.43	12.11	20.69	127.72	127.92
35	4963	179.98	192.65	165.64	0.24	0.14	0.76	76.18	-9.21	12.17	20.26	127.73	127.90
35	5285	171.38	182.22	158.70	0.24	0.13	0.71	72.55	-8.04	10.74	20.26	127.76	127.91
35	5039	180.81	197.24	168.67	0.26	0.15	0.77	77.52	-10.76	12.49	20.37	127.73	127.86
40	7114	173.10	187.73	164.18	0.27	0.13	0.74	74.30	-9.37	10.27	21.82	127.70	127.82
40	6905	179.41	190.47	172.14	0.27	0.10	0.75	75.71	-7.16	7.99	21.91	127.76	127.87
40	6959	172.57	184.11	162.04	0.25	0.12	0.72	73.22	-8.03	9.89	21.59	127.71	127.87
45	10198	176.94	194.59	164.70	0.26	0.16	0.76	76.46	-11.45	13.04	24.56	127.44	127.70
45	9497	168.94	181.61	160.48	0.27	0.12	0.71	72.26	-8.30	9.32	23.62	127.63	127.79
45	9621	172.90	189.65	161.51	0.27	0.15	0.74	74.74	-10.89	12.35	23.87	127.50	127.73
50	14367	178.66	197.41	165.38	0.26	0.17	0.77	77.34	-12.17	13.98	28.21	127.15	127.55
50	12974	181.09	199.37	169.59	0.27	0.16	0.78	78.13	-11.62	12.90	27.29	127.29	127.59
50	12965	185.72	202.67	170.80	0.26	0.16	0.80	79.39	-11.46	14.05	27.62	127.20	127.64

Table 2. Summary of ANFIS Training Data

Y	CB	CR	PIXEL COUNT	OUTPUT
198.0159	127.9673	127.9821	1170.014	30
198.0552	127.9678	127.9837	1180.027	30
198.0692	127.9645	127.9789	1192.995	30
198.0379	127.971	127.9849	1179.013	30
198.0525	127.966	127.9906	1095.549	30
197.8803	127.973	127.9883	1194.226	30
198.0423	127.9825	127.9905	1192.181	30
197.9636	127.9792	127.9912	1190.607	30
197.8638	127.9778	127.9862	1177.112	30
197.8237	127.9798	127.9919	1142.217	30
198.0399	127.9393	127.9601	1192.84	30
197.9994	127.9504	127.9714	1178.792	30
198.0198	127.9445	127.9759	1095.345	30
197.8561	127.9569	127.9643	1194.079	30
198.0085	127.9589	127.9731	1192.057	30
197.9428	127.9604	127.9671	1190.435	30
197.8338	127.9538	127.9682	1176.986	30
197.7976	127.9627	127.9722	1142.092	30
198.2954	127.9431	127.9745	1490.704	32
198.289	127.9481	127.9803	1503.567	32
198.3717	127.9387	127.972	1556.951	32
198.2913	127.9467	127.9783	1496.327	32
198.3305	127.9411	127.9779	1487.833	32
198.2462	127.9457	127.979	1523.723	32
198.326	127.95	127.979	1520.931	32
198.2677	127.95	127.9811	1507.063	32
198.2159	127.949	127.9777	1493.526	32
198.2004	127.9504	127.9814	1491.351	32
198.3337	127.9203	127.9516	1556.674	32
198.2635	127.9218	127.9538	1496.141	32
198.3061	127.9214	127.9529	1487.58	32
198.2181	127.9216	127.959	1523.501	32
198.2966	127.9336	127.9567	1520.719	32
198.234	127.9285	127.9649	1506.806	32
198.1768	127.9248	127.9616	1493.317	32
198.1622	127.9274	127.9574	1491.158	32
198.5763	127.9186	127.9668	1815.777	34
198.524	127.9278	127.9768	1829.641	34
198.6768	127.9124	127.9647	1924.776	34
198.5478	127.9222	127.9715	1818.724	34
202.1497	127.7231	127.8703	5962.37	50
202.3196	127.7598	127.8834	6049.221	50
201.9334	127.7355	127.8686	5969.884	50
202.237	127.7428	127.878	6004.928	50
202.0357	127.73	127.8641	5962.609	50
202.0727	127.7471	127.8794	6008.449	50
202.0417	127.712	127.8721	5982.536	50
202.1517	127.7303	127.8715	6006.19	50
202.1655	127.7191	127.8706	5982.773	50
202.2748	127.7287	127.8705	6003.325	50
201.9102	127.7105	127.8515	5968.742	50
202.1968	127.7218	127.8612	6003.74	50
202.0115	127.7089	127.841	5961.418	50
202.0498	127.7318	127.8575	6007.384	50
202.0104	127.6975	127.8543	5981.581	50
202.1199	127.7061	127.8497	6005.189	50
202.1362	127.6951	127.8552	5981.704	50
202.242	127.7122	127.8576	6002.507	50
202.2389	127.7219	127.8661	6455.676	50
202.4554	127.7632	127.8809	6459.771	50
202.3553	127.7206	127.8456	6532.194	50
202.3477	127.7438	127.8751	6457.702	50
202.2642	127.722	127.855	6484.417	50
202.3015	127.7449	127.8684	6463.244	50
202.2753	127.7047	127.8635	6457.24	50
202.2911	127.7267	127.8659	6444.27	50
202.2813	127.7146	127.8651	6456.69	50
202.4332	127.7249	127.8648	6446.652	50
202.3314	127.6956	127.8236	6531.35	50
202.3202	127.7275	127.8547	6456.705	50
202.2238	127.7025	127.8316	6483.571	50
202.2801	127.7215	127.8529	6462.384	50
202.246	127.6811	127.8499	6456.311	50
202.256	127.7092	127.8425	6443.258	50
202.243	127.7014	127.8441	6455.538	50
202.4088	127.7092	127.8464	6445.471	50
202.3285	127.7163	127.8619	6959.625	50
202.5911	127.7666	127.8785	6906.06	50
202.8174	127.696	127.822	7113.628	50
202.4563	127.7422	127.8717	6934.931	50

198.6171	127.9155	127.9653	1882.784	34
198.6124	127.9184	127.9697	1866.113	34
198.6145	127.9173	127.9676	1863.203	34
198.5754	127.9207	127.9709	1837.748	34
198.5699	127.9202	127.9691	1814.865	34
198.5783	127.9208	127.971	1848.89	34
198.6532	127.8919	127.9395	1924.45	34
198.5101	127.9038	127.9473	1818.502	34
198.5776	127.8965	127.9434	1882.501	34
198.5776	127.9005	127.9558	1865.81	34
198.5765	127.9004	127.9431	1863	34
198.5496	127.9023	127.9536	1837.56	34
198.5401	127.9049	127.9558	1814.548	34
198.5456	127.9047	127.9563	1848.675	34
198.8623	127.8932	127.9589	2154.833	36
198.7637	127.9061	127.973	2164.34	36
198.9914	127.8851	127.9564	2305.356	36
198.8118	127.8969	127.9645	2155.905	36
198.9199	127.8885	127.9527	2286.002	36
198.9793	127.8907	127.9603	2231.799	36
198.9129	127.8845	127.9562	2229.993	36
198.8909	127.8911	127.9607	2192.95	36
198.9284	127.891	127.9605	2151.887	36
198.9585	127.8909	127.9605	2223.125	36
198.9608	127.8632	127.9358	2305.007	36
198.781	127.8814	127.9427	2155.595	36
198.8838	127.8736	127.9317	2285.725	36
198.9419	127.8755	127.9394	2231.43	36
198.8921	127.8639	127.9417	2229.755	36
198.867	127.8706	127.9477	2192.661	36
198.8929	127.8763	127.939	2151.57	36
198.9195	127.8688	127.9451	2222.694	36
199.1628	127.8662	127.9506	2528.421	38
199.0165	127.882	127.9683	2521.75	38
199.3307	127.8554	127.9462	2718.274	38
199.09	127.8704	127.9571	2526.501	38
199.2472	127.8598	127.9403	2709.6	38
199.3484	127.8624	127.9507	2631.359	38
199.2285	127.8516	127.9447	2632.574	38
199.2195	127.861	127.9504	2582.283	38
199.2956	127.8614	127.9518	2527.007	38
199.3428	127.8606	127.95	2624.457	38
199.2974	127.8366	127.9317	2717.868	38

202.5276	127.706	127.8436	7030.865	50
202.5959	127.7372	127.8547	6972.862	50
202.5687	127.6958	127.8517	6984.629	50
202.472	127.7215	127.8593	6935.249	50
202.4276	127.7084	127.8589	6949.534	50
202.6107	127.7197	127.8584	6941.592	50
202.777	127.6777	127.7979	7112.35	50
202.4162	127.7233	127.8563	6934.154	50
202.5005	127.6895	127.8206	7029.736	50
202.5711	127.716	127.8352	6971.54	50
202.5453	127.6748	127.8367	6983.458	50
202.4347	127.7017	127.8464	6934.464	50
202.4054	127.6952	127.8348	6948.326	50
202.5787	127.7056	127.842	6940.635	50
202.4305	127.7012	127.8573	7431.448	52
202.7258	127.7699	127.876	7354.616	52
203.2787	127.6615	127.8003	7658.453	52
202.5699	127.7351	127.8672	7396.08	52
202.8408	127.6793	127.829	7545.257	52
202.957	127.7206	127.839	7504.144	52
202.917	127.6837	127.8362	7526.945	52
202.7218	127.7127	127.8508	7449.26	52
202.6262	127.699	127.8509	7417	52
202.8254	127.7115	127.8503	7455.562	52
203.2519	127.637	127.7816	7657.592	52
202.5303	127.7136	127.8508	7394.875	52
202.813	127.6573	127.8096	7543.79	52
202.9362	127.7072	127.8138	7502.707	52
202.8919	127.6689	127.8177	7526.028	52
202.6875	127.6981	127.8292	7448.313	52
202.6058	127.6771	127.8329	7415.758	52
202.7965	127.6921	127.8327	7454.157	52
202.6186	127.6707	127.8496	7934.426	54
202.8585	127.7705	127.8733	7837.803	54
203.787	127.6154	127.7765	8235.248	54
202.7366	127.7177	127.8597	7887.433	54
203.2505	127.6408	127.8106	8068.159	54
203.3738	127.6926	127.822	8021.94	54
203.3211	127.6658	127.8169	8046.206	54
203.0674	127.698	127.8392	7953.913	54
202.8997	127.684	127.84	7912.232	54
203.1006	127.6977	127.8394	7954.268	54
203.7651	127.5986	127.7606	8233.995	54

199.0599	127.8553	127.9372	2526.184	38
199.2172	127.8419	127.9223	2709.231	38
199.3218	127.8461	127.9371	2630.905	38
199.2061	127.8283	127.925	2632.166	38
199.1879	127.8359	127.9281	2581.869	38
199.268	127.8435	127.9349	2526.637	38
199.3053	127.8415	127.929	2624.09	38
199.5058	127.8366	127.942	2968.004	40
199.3128	127.8542	127.9617	2926.976	40
199.7191	127.8225	127.9331	3190.05	40
199.4102	127.8425	127.9492	2952.627	40
199.6215	127.8293	127.9284	3170.654	40
199.7229	127.833	127.9404	3071.109	40
199.5746	127.819	127.9333	3078.618	40
199.5732	127.8306	127.9402	3014.722	40
199.6757	127.8315	127.9431	2966.59	40
199.7312	127.83	127.9396	3059.182	40
199.6926	127.7995	127.9155	3189.549	40
199.387	127.8218	127.9285	2952.267	40
199.5817	127.8112	127.9104	3170.061	40
199.6889	127.8108	127.9189	3070.525	40
199.5445	127.8038	127.908	3078.035	40
199.5448	127.8092	127.9159	3014.254	40
199.6523	127.8136	127.9198	2966.247	40
199.698	127.8153	127.9262	3058.644	40
200.0026	127.8034	127.933	3532.596	42
199.7932	127.8205	127.9494	3435.379	42
200.1941	127.7853	127.9158	3748.8	42
199.8977	127.8124	127.9402	3483.837	42
200.1074	127.7954	127.9175	3674.842	42
200.1063	127.8022	127.9294	3591.625	42
200.0278	127.7877	127.9223	3612.597	42
200.0055	127.8004	127.9303	3539.875	42
200.07	127.8018	127.9345	3507.463	42
200.1192	127.7998	127.9297	3552.728	42
200.1631	127.7684	127.8989	3748.104	42
199.868	127.7871	127.9147	3483.332	42
200.0803	127.7798	127.8981	3674.31	42
200.0715	127.7878	127.9081	3590.941	42
200.0057	127.7735	127.904	3612.18	42
199.9782	127.7774	127.9111	3539.33	42
200.0414	127.7826	127.9133	3507.095	42
200.0947	127.7765	127.9057	3552.088	42

202.7035	127.7043	127.8407	7886.048	54
203.2284	127.6265	127.7929	8066.808	54
203.3451	127.6714	127.7983	8020.776	54
203.2939	127.6462	127.7997	8044.974	54
203.0397	127.6818	127.8178	7952.887	54
202.8765	127.6658	127.8156	7911.254	54
203.0741	127.6848	127.8202	7953.238	54
203.0945	127.6233	127.8264	8473.706	56
203.0765	127.7548	127.8654	8361.832	56
204.3445	127.5599	127.7507	8858.005	56
203.107	127.6855	127.8432	8418.078	56
203.7744	127.5915	127.7885	8652.752	56
203.8438	127.6521	127.8021	8568.765	56
203.8189	127.6396	127.7948	8599.286	56
203.5336	127.6748	127.8232	8477.159	56
203.2716	127.6607	127.8251	8446.118	56
203.4585	127.6757	127.8244	8475.483	56
204.3106	127.5394	127.735	8856.993	56
203.081	127.6723	127.8289	8417.03	56
203.7518	127.5692	127.7709	8651.72	56
203.8181	127.6287	127.7884	8567.409	56
203.7823	127.6179	127.7725	8598.12	56
203.5041	127.6538	127.8002	8475.729	56
203.2448	127.6443	127.8045	8444.807	56
203.4336	127.6579	127.8028	8474.514	56
203.9375	127.564	127.7764	9033.789	58
203.736	127.7021	127.8373	8915.612	58
204.9352	127.4989	127.724	9509.938	58
203.824	127.6351	127.8091	8975.018	58
204.4176	127.5349	127.761	9284.359	58
204.4057	127.5982	127.7768	9199.975	58
204.4172	127.5995	127.7679	9236.699	58
204.1384	127.6377	127.8005	9079.677	58
203.7938	127.6239	127.8034	9004.629	58
203.9484	127.6397	127.8024	9077.274	58
204.9079	127.4752	127.7096	9508.612	58
203.7919	127.6213	127.7927	8973.255	58
204.388	127.5097	127.7377	9282.665	58
204.3814	127.5826	127.7529	9198.474	58
204.3843	127.5753	127.7456	9235.313	58
204.1166	127.6127	127.7755	9078.218	58
203.7638	127.6042	127.7796	9002.923	58
203.9142	127.6178	127.7877	9075.933	58

200.7192	127.7689	127.924	4224.496	44
200.5199	127.7828	127.9297	4065.9	44
200.7498	127.7471	127.8959	4368.687	44
200.6219	127.7803	127.9299	4140.199	44
200.7153	127.7594	127.9086	4211.299	44
200.5007	127.7704	127.9172	4200.309	44
200.6609	127.7604	127.9123	4241.776	44
200.5487	127.7723	127.9212	4166.225	44
200.4768	127.7739	127.9261	4177.34	44
200.4943	127.7718	127.9207	4125.471	44
200.7235	127.7263	127.8749	4368.159	44
200.5915	127.7567	127.9061	4139.393	44
200.6882	127.7401	127.883	4210.559	44
200.462	127.7536	127.9016	4199.523	44
200.6291	127.7446	127.8896	4241.263	44
200.5187	127.7494	127.9043	4165.401	44
200.4544	127.7553	127.9011	4176.839	44
200.4641	127.7511	127.8986	4124.962	44
201.1794	127.7411	127.9159	4841.873	46
200.9249	127.7524	127.9137	4639.628	46
201.2421	127.7177	127.8793	4903.688	46
201.0551	127.7509	127.9188	4743.091	46
201.2229	127.7291	127.903	4748.975	46
200.8851	127.7416	127.9046	4769.763	46
201.1747	127.741	127.9045	4827.107	46
200.9903	127.7497	127.9137	4753.196	46
200.8679	127.7511	127.9185	4795.119	46
200.8258	127.7497	127.9135	4694.028	46
201.2088	127.7042	127.8659	4903.034	46
201.0291	127.7359	127.8936	4742.384	46
201.1866	127.7149	127.8804	4748.115	46
200.8527	127.7255	127.885	4768.815	46
201.1465	127.7251	127.885	4826.412	46
200.9505	127.7357	127.8957	4752.494	46
200.8444	127.7278	127.8943	4794.606	46
200.7924	127.7297	127.8881	4693.277	46
201.3376	127.7262	127.9093	5150.684	48
201.0948	127.7378	127.9068	4945.835	48
201.501	127.7041	127.8725	5199.478	48
201.2141	127.732	127.9093	5053.918	48
201.4352	127.7138	127.9009	5141.749	48
201.1909	127.7234	127.8947	5090.569	48
201.342	127.7324	127.8997	5143.478	48

204.8688	127.5008	127.7283	9620.193	60
204.6158	127.6258	127.7919	9496.001	60
205.5554	127.4367	127.6966	10198.2	60
204.7225	127.569	127.7618	9557.394	60
205.1637	127.4717	127.7276	9943.745	60
205.0581	127.5337	127.7462	9903.912	60
205.1071	127.5399	127.7359	9944.652	60
204.8611	127.5816	127.7688	9751.139	60
204.4903	127.5685	127.7726	9587.947	60
204.614	127.584	127.7706	9748.41	60
205.526	127.4151	127.6825	10196.87	60
204.6995	127.5445	127.7421	9555.916	60
205.1351	127.4551	127.7081	9942.542	60
205.0357	127.5101	127.727	9902.551	60
205.0708	127.5156	127.7214	9943.463	60
204.8326	127.5623	127.7526	9749.247	60
204.4559	127.5446	127.7596	9586.185	60
204.583	127.5592	127.7518	9746.554	60
205.7007	127.4384	127.7005	10308.66	62
205.4055	127.5534	127.7487	10160.69	62
206.2777	127.3735	127.6648	11018.89	62
205.5737	127.4957	127.7215	10232.44	62
205.9724	127.4053	127.6907	10650.13	62
205.7838	127.4641	127.7111	10659.34	62
205.8644	127.4616	127.7004	10699.59	62
205.6515	127.507	127.729	10472.12	62
205.3374	127.4948	127.7341	10268.05	62
205.4481	127.5085	127.7296	10468.44	62
206.2409	127.3505	127.6463	11017.58	62
205.5337	127.4809	127.7075	10230.73	62
205.9314	127.3801	127.669	10649.03	62
205.7569	127.445	127.6937	10658.1	62
205.8352	127.4474	127.6772	10698.21	62
205.6196	127.4909	127.7145	10470.09	62
205.3163	127.4706	127.7203	10266.94	62
205.4135	127.4847	127.7058	10467.34	62
206.4848	127.3749	127.6822	11056.23	64
206.1513	127.4858	127.7088	10891.72	64
207.0713	127.3091	127.6306	11928.41	64
206.3408	127.4246	127.6921	10971.57	64
206.7891	127.3399	127.6553	11452.89	64
206.5514	127.3954	127.6736	11436.24	64
206.6519	127.3751	127.6645	11469.4	64

201.1915	127.7365	127.9084	5077.075	48
201.1886	127.7372	127.9122	5107.568	48
201.077	127.7371	127.9087	5058.667	48
201.4664	127.6797	127.8513	5198.572	48
201.1762	127.7158	127.893	5053.395	48
201.4014	127.7003	127.8758	5141.176	48
201.1627	127.7061	127.8797	5089.996	48
201.3053	127.7122	127.8819	5142.857	48
201.1613	127.7224	127.8835	5076.359	48
201.1536	127.7154	127.8901	5106.563	48
201.0382	127.7211	127.8895	5057.839	48
201.4337	127.721	127.9041	5194.816	50
201.233	127.7349	127.9035	5049.011	50
201.5429	127.7033	127.8749	5258.78	50
201.3307	127.7257	127.9028	5121.905	50
201.4795	127.7114	127.9007	5265.996	50
201.3588	127.7187	127.8905	5153.274	50
201.3938	127.7326	127.8976	5185.287	50
201.307	127.7327	127.9048	5139.124	50
201.4039	127.7321	127.9073	5158.087	50
201.2435	127.7339	127.9056	5154.892	50
201.5191	127.6901	127.8566	5257.767	50
201.3016	127.7063	127.8788	5121.137	50
201.4468	127.6912	127.8874	5265.337	50
201.3227	127.7057	127.8699	5152.256	50
201.3551	127.7154	127.8772	5184.28	50
201.2775	127.7126	127.8797	5138.134	50
201.37	127.7178	127.8884	5157.484	50
201.2082	127.7151	127.8926	5154.123	50
201.5236	127.7202	127.8996	5127.97	50
201.3689	127.7367	127.9009	5079.76	50
201.4796	127.7086	127.8825	5185.231	50
201.4442	127.7262	127.8985	5100.325	50
201.4818	127.7143	127.9003	5192.385	50
201.4292	127.722	127.8908	5104.45	50
201.4322	127.7358	127.8966	5110.881	50
201.4104	127.7341	127.9019	5093.786	50
201.536	127.732	127.903	5110.869	50
201.3616	127.7355	127.9028	5115.307	50
201.4442	127.6901	127.8679	5184.378	50
201.4129	127.711	127.8838	5099.337	50
201.4481	127.6926	127.8845	5191.43	50
201.3893	127.6987	127.8735	5103.574	50

206.45	127.4225	127.686	11214.8	64
206.2594	127.4114	127.6944	11011.22	64
206.3737	127.4225	127.6852	11208.43	64
207.0366	127.2907	127.6145	11926.33	64
206.3084	127.4088	127.6672	10970.44	64
206.7618	127.3219	127.6304	11451.46	64
206.529	127.3712	127.6515	11434.49	64
206.6175	127.3602	127.6411	11467.75	64
206.413	127.4019	127.6658	11213.01	64
206.2246	127.3899	127.6746	11009.49	64
206.3366	127.4031	127.6713	11206.62	64
207.2358	127.3135	127.6669	11789.16	66
206.8757	127.4174	127.6691	11637.58	66
207.8664	127.2493	127.5986	12841.65	66
207.0593	127.3615	127.6676	11711.83	66
207.5685	127.2791	127.6262	12279.85	66
207.3222	127.3321	127.6364	12199.09	66
207.4289	127.2949	127.6315	12217.2	66
207.2105	127.341	127.6463	11945.67	66
207.1644	127.3308	127.6607	11748.81	66
207.2794	127.3399	127.6447	11934.04	66
207.8358	127.2362	127.5772	12840.27	66
207.019	127.3396	127.6453	11710.03	66
207.5356	127.2635	127.602	12277.58	66
207.289	127.3089	127.6181	12197.02	66
207.3928	127.2783	127.6119	12215.47	66
207.1794	127.3239	127.6236	11944.41	66
207.1237	127.3167	127.644	11747.6	66
207.2501	127.3211	127.6274	11932.21	66
207.9428	127.2567	127.6544	12438.96	68
207.5861	127.3514	127.6308	12344.44	68
208.5954	127.1971	127.5721	13673.46	68
207.7547	127.3075	127.6444	12391.37	68
208.2847	127.2253	127.6054	13047.38	68
208.0611	127.2766	127.6019	12917.73	68
208.1625	127.2292	127.6039	12927.12	68
207.9093	127.2709	127.6135	12630.2	68
207.9909	127.2613	127.6359	12414.87	68
208.0882	127.2697	127.6122	12616.22	68
208.5634	127.1785	127.5496	13671.53	68
207.731	127.2905	127.62	12389.57	68
208.2505	127.2019	127.5923	13044.96	68
208.0324	127.2515	127.5819	12916.39	68

201.4044	127.7124	127.8805	5110.185	50
201.3706	127.7187	127.8871	5093.206	50
201.4992	127.7067	127.8793	5110.194	50
201.3322	127.7213	127.88	5114.497	50
201.6131	127.7206	127.8953	5040.679	50
201.5047	127.7397	127.8984	5098.1	50
201.3862	127.7157	127.8915	5065.292	50
201.5577	127.7288	127.8952	5066.324	50
201.4825	127.7184	127.8983	5065.949	50
201.4738	127.7272	127.8928	5049.204	50
201.4722	127.7376	127.8954	5031.69	50
201.5128	127.7364	127.8986	5044.735	50
201.6294	127.7327	127.8988	5050.54	50
201.4699	127.7376	127.8994	5059.052	50
201.3522	127.6937	127.8748	5064.405	50
201.5319	127.7126	127.8767	5065.565	50
201.4587	127.6971	127.8783	5064.991	50
201.4508	127.71	127.8758	5048.336	50
201.449	127.7193	127.8713	5030.875	50
201.4922	127.7184	127.8803	5044.006	50
201.602	127.7155	127.8792	5049.559	50
201.4491	127.7169	127.8809	5058.249	50
201.7025	127.7212	127.8912	4975.922	50
201.6405	127.7431	127.8959	5126.977	50
201.3017	127.7232	127.8998	4956.772	50
201.6711	127.7315	127.8922	5050.406	50
201.4964	127.7224	127.8948	4967.949	50
201.5246	127.7322	127.8947	5028.931	50
201.5172	127.737	127.8935	4991.876	50
201.6152	127.7378	127.8948	5032.754	50
201.7121	127.7326	127.8945	5012.121	50
201.5846	127.7386	127.8955	5039.425	50
201.2785	127.7017	127.8774	4955.987	50
201.6455	127.7089	127.8746	5049.852	50
201.4631	127.7029	127.871	4967.238	50
201.4946	127.7153	127.8758	5028.027	50
201.4929	127.7175	127.8723	4991.125	50
201.5791	127.7134	127.8763	5032.088	50
201.6892	127.7129	127.8696	5011.547	50
201.5569	127.7138	127.8768	5038.801	50
201.792	127.7216	127.887	4965.117	50
201.7763	127.7464	127.8934	5182.786	50
201.2541	127.7302	127.9052	4908.946	50

208.1283	127.2147	127.5878	12925.04	68
207.8801	127.2573	127.5998	12628.88	68
207.9612	127.2437	127.612	12412.49	68
208.0546	127.252	127.5957	12613.82	68
208.615	127.2044	127.6437	12965.31	70
208.2902	127.2891	127.5943	12974.32	70
209.2158	127.1526	127.5529	14366.97	70
208.4378	127.2521	127.6216	12970.36	70
208.9221	127.1796	127.5917	13690.83	70
208.7687	127.2255	127.5708	13607.66	70
208.8514	127.1776	127.5815	13607.81	70
208.5838	127.213	127.5874	13254.97	70
208.7365	127.2038	127.6182	12968.6	70
208.7887	127.2124	127.5868	13269.84	70
209.186	127.1288	127.5347	14365.32	70
208.3975	127.2381	127.6075	12967.94	70
208.8839	127.1626	127.5725	13688.46	70
208.7411	127.2091	127.5576	13605.05	70
208.8153	127.1581	127.5654	13605.77	70
208.5602	127.1962	127.5648	13252.92	70
208.6952	127.1907	127.598	12966.73	70
208.7621	127.187	127.567	13268.07	70
209.266	127.1554	127.6341	13363.56	70
208.992	127.23	127.5589	13514.74	70
209.7191	127.1141	127.5409	14907.05	70
209.1157	127.1948	127.5988	13439.98	70
209.489	127.1379	127.5831	14182.98	70
209.4202	127.1732	127.5449	14225.85	70
209.4765	127.1356	127.564	14200.04	70
209.2568	127.1642	127.566	13826.42	70
209.4013	127.155	127.6048	13402.96	70
209.4048	127.1642	127.566	13852.75	70
209.6835	127.1011	127.5278	14905.13	70
209.0763	127.1787	127.5844	13437.65	70
209.4543	127.1181	127.5634	14180.24	70
209.3816	127.1541	127.5318	14223.07	70
209.4347	127.1178	127.5476	14198.04	70
209.2287	127.1463	127.5437	13824.23	70
209.367	127.1415	127.5842	13401.41	70
209.3799	127.147	127.5477	13850.68	70
209.9066	127.1085	127.625	13654.91	70
209.6933	127.1732	127.5243	13974.9	70
210.1225	127.0794	127.5344	15312.67	70

201.7845	127.734	127.8894	5074.385	50
201.5327	127.7262	127.8903	4939.43	50
201.5875	127.7366	127.8956	5061.644	50
201.5714	127.7344	127.891	5010.967	50
201.7178	127.738	127.8907	5072.725	50
201.7945	127.7315	127.89	5020.195	50
201.7079	127.7384	127.891	5072.562	50
201.2155	127.7096	127.8903	4908.077	50
201.7476	127.7139	127.8724	5073.545	50
201.5042	127.7125	127.8769	4938.807	50
201.5633	127.7214	127.8796	5060.689	50
201.5479	127.721	127.867	5010.03	50
201.6921	127.7227	127.8741	5071.767	50
201.7582	127.714	127.8645	5019.516	50
201.683	127.7172	127.8713	5071.819	50
201.8814	127.722	127.8828	5039.025	50
201.9122	127.7498	127.8909	5284.605	50
201.2702	127.7363	127.9059	4963.363	50
201.898	127.7364	127.8865	5162.599	50
201.5991	127.7295	127.8848	5008.522	50
201.6672	127.7404	127.895	5164.443	50
201.6409	127.7301	127.8877	5107.721	50
201.8208	127.7371	127.8862	5180.073	50
201.8808	127.7294	127.8853	5101.648	50
201.8408	127.7369	127.8862	5174.789	50
201.2479	127.7161	127.8838	4962.573	50
201.8654	127.7218	127.8628	5161.996	50
201.5673	127.7145	127.86	5007.806	50
201.6294	127.7187	127.8798	5163.47	50
201.6071	127.7145	127.8639	5107.125	50
201.7987	127.7156	127.872	5179.129	50
201.8408	127.716	127.8704	5100.8	50
201.8109	127.7213	127.8669	5173.781	50
201.9709	127.7224	127.8786	5225.634	50
202.048	127.7531	127.8884	5454.035	50
201.378	127.7407	127.9003	5153.331	50
202.0113	127.7387	127.8837	5340.062	50
201.7026	127.7319	127.8786	5198.767	50
201.7684	127.7437	127.8924	5352.077	50
201.735	127.7247	127.8837	5297.924	50
201.9253	127.7353	127.8815	5367.726	50
201.9708	127.7264	127.8805	5283.142	50
201.9808	127.7346	127.8811	5360.02	50

209.7918	127.1384	127.576	13815.59	70
210.0048	127.0947	127.5781	14533.23	70
209.9918	127.1228	127.5243	14727.28	70
210.0257	127.1004	127.5512	14660.18	70
209.9009	127.1226	127.5481	14301.46	70
209.9947	127.1132	127.5942	13736.3	70
209.9509	127.123	127.5485	14321.35	70
210.0905	127.0551	127.5173	15310.04	70
209.7552	127.1161	127.5534	13813.82	70
209.9636	127.0748	127.5625	14530.61	70
209.9658	127.1074	127.5034	14724.76	70
209.9878	127.0815	127.5308	14658.11	70
209.8713	127.1069	127.5233	14299.99	70
209.9722	127.0962	127.5811	13734.71	70
209.9275	127.1084	127.5261	14319.74	70
210.5427	127.0626	127.6161	13870.21	70
210.3944	127.1176	127.4899	14374.68	70
210.4539	127.0467	127.5317	15618.6	70
210.4672	127.0854	127.5533	14122.82	70
210.4889	127.0525	127.5752	14772.34	70
210.4833	127.0766	127.5082	15092.47	70
210.5051	127.0693	127.5417	14973.47	70
210.4974	127.0855	127.5323	14653.23	70
210.5395	127.0757	127.585	13997.12	70
210.4515	127.086	127.5328	14656.96	70
210.427	127.0286	127.5132	15616.25	70
210.4387	127.061	127.5287	14120.44	70
210.4553	127.0366	127.5528	14770.8	70
210.4461	127.052	127.4888	15090.63	70
210.467	127.0446	127.5236	14971.06	70
210.4612	127.0604	127.5161	14651.68	70
210.5	127.0555	127.5605	13994.79	70
210.4179	127.0682	127.5127	14655.32	70
211.1772	127.0171	127.6073	14037.75	70
211.0955	127.0626	127.4558	14734.74	70
210.7396	127.015	127.5312	15859.6	70
211.1425	127.0373	127.5305	14386.35	70
210.9554	127.0137	127.5733	14935.55	70
210.9096	127.0362	127.4951	15327.13	70
210.9301	127.0401	127.5342	15151.19	70
211.0397	127.0508	127.5176	14877.5	70
211.057	127.0405	127.5765	14212.13	70
210.9278	127.0512	127.5179	14865.46	70

201.3465	127.7172	127.8868	5152.77	50
201.9875	127.7161	127.8614	5339.224	50
201.6705	127.712	127.8585	5198.049	50
201.7338	127.7183	127.8715	5351.52	50
201.7005	127.7032	127.8703	5297.1	50
201.8993	127.7103	127.866	5366.911	50
201.9477	127.7053	127.8596	5282.132	50
201.9534	127.7206	127.868	5359.364	50
202.0603	127.7229	127.8744	5538.111	50
202.1838	127.7565	127.8859	5708.086	50
201.5988	127.7413	127.8876	5494.068	50
202.1245	127.7409	127.8808	5622.509	50
201.8477	127.7325	127.8718	5521.068	50
201.8995	127.7461	127.8874	5633.654	50
201.8647	127.7186	127.8786	5590.443	50
202.0337	127.733	127.8766	5643.407	50
202.0647	127.723	127.8756	5579.752	50
202.1254	127.7319	127.8759	5636.625	50
201.5706	127.7254	127.8626	5493.242	50
202.0959	127.7211	127.8646	5621.559	50
201.8082	127.7134	127.8476	5520.274	50
201.861	127.725	127.8672	5632.911	50
201.8278	127.7036	127.854	5589.464	50
202.0058	127.7188	127.8533	5642.573	50
202.0295	127.7071	127.8514	5579.075	50
202.0975	127.714	127.8599	5635.754	50

210.7168	126.9936	127.5174	15856.6	70
211.1132	127.0176	127.5168	14383.84	70
210.9239	126.9958	127.5497	14933.58	70
210.8713	127.0155	127.4775	15324.89	70
210.8879	127.0175	127.5214	15149.35	70
211.0057	127.035	127.4973	14875.34	70
211.0179	127.0213	127.5579	14210.62	70
210.9001	127.0321	127.5046	14862.95	70
211.8111	126.9718	127.5985	14177.84	70
211.7966	127.0078	127.4217	15070.97	70
210.9987	126.9838	127.532	16061.94	70
211.8178	126.9946	127.5077	14624.76	70
211.4133	126.9804	127.5718	15052.38	70
211.2904	127.002	127.4839	15453.5	70
211.318	127.0118	127.5277	15220.03	70
211.5309	127.0172	127.5033	14988.26	70
211.5614	127.0063	127.5682	14401.09	70
211.3932	127.0172	127.5034	14968.72	70
210.9666	126.9697	127.5156	16060.07	70
211.7854	126.9811	127.4945	14621.86	70
211.3738	126.9564	127.5529	15050.37	70
211.2607	126.9879	127.4612	15451.49	70
211.277	126.9984	127.5075	15217.94	70
211.5034	127.0008	127.4795	14986.57	70
211.5372	126.9813	127.5548	14399.31	70
211.3679	127.0015	127.4853	14966.62	70

Table 3. Summary of Normalized Training Data

Y	CB	CR	PIXEL	OUTPUT
0.02	0.99	0.98	0.00	0.00
0.02	0.99	0.99	0.01	0.00
0.02	0.98	0.98	0.01	0.00
0.02	0.99	0.99	0.01	0.00
0.02	0.98	1.00	0.00	0.00
0.01	0.99	0.99	0.01	0.00
0.02	1.00	1.00	0.01	0.00
0.01	1.00	1.00	0.01	0.00
0.00	1.00	0.99	0.01	0.00
0.00	1.00	1.00	0.00	0.00
0.02	0.96	0.94	0.01	0.00
0.01	0.97	0.96	0.01	0.00
0.02	0.96	0.97	0.00	0.00
0.00	0.98	0.95	0.01	0.00
0.02	0.98	0.97	0.01	0.00
0.01	0.98	0.96	0.01	0.00
0.00	0.97	0.96	0.01	0.00
0.00	0.98	0.97	0.00	0.00
0.04	0.96	0.97	0.03	0.05
0.04	0.97	0.98	0.03	0.05
0.04	0.96	0.97	0.03	0.05
0.04	0.97	0.98	0.03	0.05
0.04	0.96	0.98	0.03	0.05
0.03	0.96	0.98	0.03	0.05
0.04	0.97	0.98	0.03	0.05
0.03	0.97	0.98	0.03	0.05
0.03	0.97	0.98	0.03	0.05
0.03	0.97	0.98	0.03	0.05
0.04	0.94	0.93	0.03	0.05
0.03	0.94	0.93	0.03	0.05
0.04	0.94	0.93	0.03	0.05
0.03	0.94	0.94	0.03	0.05
0.04	0.95	0.94	0.03	0.05
0.03	0.95	0.95	0.03	0.05
0.03	0.94	0.95	0.03	0.05
0.03	0.95	0.94	0.03	0.05
0.06	0.94	0.96	0.05	0.10
0.05	0.95	0.97	0.05	0.10
0.06	0.93	0.95	0.06	0.10
0.05	0.94	0.96	0.05	0.10

Y	CB	CR	PIXEL	OUTPUT
0.31	0.75	0.79	0.33	0.50
0.32	0.78	0.81	0.33	0.50
0.29	0.76	0.78	0.33	0.50
0.32	0.77	0.80	0.33	0.50
0.30	0.75	0.78	0.33	0.50
0.30	0.77	0.80	0.33	0.50
0.30	0.74	0.79	0.33	0.50
0.31	0.75	0.79	0.33	0.50
0.31	0.74	0.79	0.33	0.50
0.32	0.75	0.79	0.33	0.50
0.29	0.73	0.75	0.33	0.50
0.31	0.75	0.77	0.33	0.50
0.30	0.73	0.74	0.33	0.50
0.30	0.76	0.76	0.33	0.50
0.30	0.72	0.76	0.33	0.50
0.31	0.73	0.75	0.33	0.50
0.31	0.72	0.76	0.33	0.50
0.32	0.74	0.76	0.33	0.50
0.32	0.75	0.78	0.36	0.50
0.33	0.79	0.81	0.36	0.50
0.33	0.74	0.74	0.36	0.50
0.32	0.77	0.80	0.36	0.50
0.32	0.75	0.76	0.36	0.50
0.32	0.77	0.78	0.36	0.50
0.32	0.73	0.77	0.36	0.50
0.32	0.75	0.78	0.36	0.50
0.32	0.74	0.78	0.36	0.50
0.33	0.75	0.78	0.36	0.50
0.32	0.72	0.70	0.36	0.50
0.32	0.75	0.76	0.36	0.50
0.32	0.73	0.72	0.36	0.50
0.32	0.75	0.76	0.36	0.50
0.32	0.71	0.75	0.36	0.50
0.32	0.73	0.74	0.36	0.50
0.32	0.73	0.74	0.36	0.50
0.33	0.73	0.74	0.36	0.50
0.32	0.74	0.77	0.39	0.50
0.34	0.79	0.80	0.39	0.50
0.36	0.72	0.70	0.40	0.50
0.33	0.77	0.79	0.39	0.50

0.06	0.93	0.95	0.05	0.10
0.06	0.94	0.96	0.05	0.10
0.06	0.94	0.96	0.05	0.10
0.06	0.94	0.96	0.05	0.10
0.06	0.94	0.96	0.05	0.10
0.06	0.94	0.96	0.05	0.10
0.06	0.91	0.91	0.06	0.10
0.05	0.92	0.92	0.05	0.10
0.06	0.92	0.92	0.05	0.10
0.06	0.92	0.94	0.05	0.10
0.06	0.92	0.91	0.05	0.10
0.05	0.92	0.93	0.05	0.10
0.05	0.92	0.94	0.05	0.10
0.05	0.92	0.94	0.05	0.10
0.08	0.91	0.94	0.07	0.15
0.07	0.93	0.97	0.07	0.15
0.09	0.91	0.94	0.08	0.15
0.07	0.92	0.95	0.07	0.15
0.08	0.91	0.93	0.08	0.15
0.08	0.91	0.94	0.08	0.15
0.08	0.90	0.94	0.08	0.15
0.08	0.91	0.95	0.07	0.15
0.08	0.91	0.94	0.07	0.15
0.08	0.91	0.94	0.08	0.15
0.08	0.88	0.90	0.08	0.15
0.07	0.90	0.91	0.07	0.15
0.08	0.89	0.89	0.08	0.15
0.08	0.90	0.91	0.08	0.15
0.08	0.88	0.91	0.08	0.15
0.08	0.89	0.92	0.07	0.15
0.08	0.90	0.91	0.07	0.15
0.08	0.89	0.92	0.08	0.15
0.10	0.89	0.93	0.10	0.20
0.09	0.90	0.96	0.10	0.20
0.11	0.88	0.92	0.11	0.20
0.09	0.89	0.94	0.10	0.20
0.10	0.88	0.91	0.11	0.20
0.11	0.88	0.93	0.10	0.20
0.10	0.87	0.92	0.10	0.20
0.10	0.88	0.93	0.10	0.20
0.11	0.88	0.93	0.10	0.20
0.11	0.88	0.93	0.10	0.20
0.11	0.86	0.89	0.11	0.20

0.34	0.73	0.74	0.40	0.50
0.34	0.76	0.76	0.39	0.50
0.34	0.72	0.75	0.39	0.50
0.33	0.75	0.77	0.39	0.50
0.33	0.73	0.77	0.39	0.50
0.34	0.74	0.77	0.39	0.50
0.36	0.70	0.66	0.40	0.50
0.33	0.75	0.76	0.39	0.50
0.34	0.71	0.70	0.40	0.50
0.34	0.74	0.73	0.39	0.50
0.34	0.70	0.73	0.39	0.50
0.33	0.73	0.74	0.39	0.50
0.33	0.72	0.72	0.39	0.50
0.34	0.73	0.74	0.39	0.50
0.33	0.73	0.76	0.42	0.55
0.35	0.79	0.80	0.42	0.55
0.39	0.69	0.66	0.44	0.55
0.34	0.76	0.78	0.42	0.55
0.36	0.70	0.71	0.43	0.55
0.37	0.74	0.73	0.43	0.55
0.37	0.71	0.73	0.43	0.55
0.35	0.74	0.75	0.42	0.55
0.34	0.72	0.75	0.42	0.55
0.36	0.74	0.75	0.42	0.55
0.39	0.66	0.63	0.44	0.55
0.34	0.74	0.75	0.42	0.55
0.36	0.68	0.68	0.43	0.55
0.37	0.73	0.69	0.43	0.55
0.36	0.69	0.69	0.43	0.55
0.35	0.72	0.71	0.42	0.55
0.34	0.70	0.72	0.42	0.55
0.36	0.72	0.72	0.42	0.55
0.34	0.70	0.75	0.46	0.60
0.36	0.79	0.79	0.45	0.60
0.43	0.64	0.62	0.48	0.60
0.35	0.74	0.77	0.45	0.60
0.39	0.67	0.68	0.47	0.60
0.40	0.72	0.70	0.46	0.60
0.39	0.69	0.69	0.46	0.60
0.38	0.72	0.73	0.46	0.60
0.36	0.71	0.73	0.46	0.60
0.38	0.72	0.73	0.46	0.60
0.43	0.63	0.59	0.48	0.60

0.09	0.88	0.90	0.10	0.20
0.10	0.86	0.88	0.11	0.20
0.11	0.87	0.90	0.10	0.20
0.10	0.85	0.88	0.10	0.20
0.10	0.86	0.89	0.10	0.20
0.10	0.86	0.90	0.10	0.20
0.11	0.86	0.89	0.10	0.20
0.12	0.86	0.91	0.13	0.25
0.11	0.87	0.95	0.12	0.25
0.14	0.84	0.90	0.14	0.25
0.12	0.86	0.93	0.12	0.25
0.13	0.85	0.89	0.14	0.25
0.14	0.85	0.91	0.13	0.25
0.13	0.84	0.90	0.13	0.25
0.13	0.85	0.91	0.13	0.25
0.13	0.85	0.91	0.13	0.25
0.14	0.85	0.91	0.13	0.25
0.14	0.82	0.87	0.14	0.25
0.11	0.84	0.89	0.12	0.25
0.13	0.83	0.86	0.14	0.25
0.13	0.83	0.87	0.13	0.25
0.12	0.83	0.85	0.13	0.25
0.12	0.83	0.87	0.13	0.25
0.13	0.84	0.87	0.13	0.25
0.14	0.84	0.88	0.13	0.25
0.16	0.83	0.90	0.16	0.30
0.14	0.84	0.93	0.16	0.30
0.17	0.81	0.87	0.18	0.30
0.15	0.83	0.91	0.16	0.30
0.16	0.82	0.87	0.17	0.30
0.16	0.82	0.89	0.17	0.30
0.16	0.81	0.88	0.17	0.30
0.16	0.82	0.89	0.16	0.30
0.16	0.82	0.90	0.16	0.30
0.17	0.82	0.89	0.16	0.30
0.17	0.79	0.84	0.18	0.30
0.15	0.81	0.86	0.16	0.30
0.16	0.80	0.84	0.17	0.30
0.16	0.81	0.85	0.17	0.30
0.16	0.80	0.85	0.17	0.30
0.16	0.80	0.86	0.16	0.30
0.16	0.81	0.86	0.16	0.30
0.16	0.80	0.85	0.16	0.30

0.35	0.73	0.73	0.45	0.60
0.39	0.65	0.65	0.47	0.60
0.40	0.70	0.66	0.46	0.60
0.39	0.67	0.66	0.46	0.60
0.37	0.71	0.69	0.46	0.60
0.36	0.69	0.69	0.46	0.60
0.38	0.71	0.70	0.46	0.60
0.38	0.65	0.71	0.49	0.65
0.38	0.78	0.78	0.49	0.65
0.47	0.59	0.58	0.52	0.65
0.38	0.71	0.74	0.49	0.65
0.43	0.62	0.64	0.50	0.65
0.43	0.68	0.67	0.50	0.65
0.43	0.67	0.65	0.50	0.65
0.41	0.70	0.70	0.49	0.65
0.39	0.69	0.71	0.49	0.65
0.40	0.70	0.71	0.49	0.65
0.46	0.57	0.55	0.52	0.65
0.38	0.70	0.71	0.49	0.65
0.42	0.60	0.61	0.50	0.65
0.43	0.66	0.64	0.50	0.65
0.43	0.64	0.62	0.50	0.65
0.41	0.68	0.66	0.49	0.65
0.39	0.67	0.67	0.49	0.65
0.40	0.68	0.67	0.49	0.65
0.44	0.59	0.62	0.53	0.70
0.42	0.73	0.73	0.52	0.70
0.51	0.53	0.53	0.56	0.70
0.43	0.66	0.68	0.53	0.70
0.47	0.56	0.60	0.55	0.70
0.47	0.63	0.62	0.54	0.70
0.47	0.63	0.61	0.54	0.70
0.45	0.66	0.66	0.53	0.70
0.43	0.65	0.67	0.53	0.70
0.44	0.67	0.67	0.53	0.70
0.51	0.51	0.50	0.56	0.70
0.43	0.65	0.65	0.53	0.70
0.47	0.54	0.55	0.55	0.70
0.47	0.61	0.58	0.54	0.70
0.47	0.60	0.57	0.54	0.70
0.45	0.64	0.62	0.53	0.70
0.43	0.63	0.63	0.53	0.70
0.44	0.64	0.64	0.53	0.70

0.21	0.79	0.88	0.21	0.35
0.19	0.81	0.89	0.20	0.35
0.21	0.77	0.83	0.22	0.35
0.20	0.80	0.89	0.20	0.35
0.21	0.78	0.85	0.21	0.35
0.19	0.79	0.87	0.21	0.35
0.20	0.78	0.86	0.21	0.35
0.20	0.80	0.88	0.21	0.35
0.19	0.80	0.88	0.21	0.35
0.19	0.79	0.88	0.20	0.35
0.21	0.75	0.79	0.22	0.35
0.20	0.78	0.85	0.20	0.35
0.21	0.76	0.81	0.21	0.35
0.19	0.78	0.84	0.21	0.35
0.20	0.77	0.82	0.21	0.35
0.19	0.77	0.85	0.21	0.35
0.19	0.78	0.84	0.21	0.35
0.19	0.77	0.84	0.20	0.35
0.24	0.76	0.87	0.25	0.40
0.22	0.78	0.86	0.24	0.40
0.25	0.74	0.80	0.25	0.40
0.23	0.77	0.87	0.24	0.40
0.24	0.75	0.84	0.24	0.40
0.22	0.77	0.85	0.25	0.40
0.24	0.76	0.85	0.25	0.40
0.23	0.77	0.86	0.24	0.40
0.22	0.77	0.87	0.25	0.40
0.22	0.77	0.86	0.24	0.40
0.24	0.73	0.78	0.25	0.40
0.23	0.76	0.83	0.24	0.40
0.24	0.74	0.80	0.24	0.40
0.22	0.75	0.81	0.25	0.40
0.24	0.75	0.81	0.25	0.40
0.22	0.76	0.83	0.24	0.40
0.22	0.75	0.83	0.25	0.40
0.21	0.75	0.82	0.24	0.40
0.25	0.75	0.86	0.27	0.45
0.24	0.76	0.85	0.26	0.45
0.26	0.73	0.79	0.27	0.45
0.24	0.76	0.86	0.26	0.45
0.26	0.74	0.84	0.27	0.45
0.24	0.75	0.83	0.27	0.45
0.25	0.76	0.84	0.27	0.45

0.50	0.53	0.54	0.57	0.75
0.49	0.65	0.65	0.56	0.75
0.55	0.47	0.48	0.61	0.75
0.49	0.60	0.60	0.57	0.75
0.53	0.50	0.54	0.59	0.75
0.52	0.56	0.57	0.59	0.75
0.52	0.57	0.55	0.59	0.75
0.50	0.61	0.61	0.58	0.75
0.48	0.60	0.62	0.57	0.75
0.49	0.61	0.61	0.58	0.75
0.55	0.45	0.46	0.61	0.75
0.49	0.57	0.56	0.57	0.75
0.52	0.49	0.50	0.59	0.75
0.52	0.54	0.54	0.59	0.75
0.52	0.55	0.53	0.59	0.75
0.50	0.59	0.58	0.58	0.75
0.47	0.57	0.59	0.57	0.75
0.48	0.59	0.58	0.58	0.75
0.56	0.47	0.49	0.62	0.80
0.54	0.58	0.57	0.61	0.80
0.60	0.41	0.43	0.66	0.80
0.55	0.53	0.53	0.61	0.80
0.58	0.44	0.47	0.64	0.80
0.57	0.49	0.51	0.64	0.80
0.58	0.49	0.49	0.64	0.80
0.56	0.54	0.54	0.63	0.80
0.54	0.52	0.55	0.61	0.80
0.55	0.54	0.54	0.63	0.80
0.60	0.38	0.39	0.66	0.80
0.55	0.51	0.50	0.61	0.80
0.58	0.41	0.43	0.64	0.80
0.57	0.48	0.48	0.64	0.80
0.57	0.48	0.45	0.64	0.80
0.56	0.52	0.51	0.63	0.80
0.54	0.50	0.52	0.61	0.80
0.54	0.51	0.50	0.63	0.80
0.62	0.41	0.46	0.67	0.85
0.60	0.52	0.50	0.65	0.85
0.66	0.34	0.37	0.72	0.85
0.61	0.46	0.47	0.66	0.85
0.64	0.37	0.41	0.69	0.85
0.62	0.43	0.44	0.69	0.85
0.63	0.41	0.43	0.69	0.85

0.24	0.76	0.85	0.27	0.45
0.24	0.76	0.86	0.27	0.45
0.23	0.76	0.85	0.26	0.45
0.26	0.70	0.75	0.27	0.45
0.24	0.74	0.83	0.26	0.45
0.26	0.72	0.80	0.27	0.45
0.24	0.73	0.80	0.27	0.45
0.25	0.74	0.81	0.27	0.45
0.24	0.75	0.81	0.27	0.45
0.24	0.74	0.82	0.27	0.45
0.23	0.75	0.82	0.26	0.45
0.26	0.75	0.85	0.27	0.50
0.25	0.76	0.85	0.26	0.50
0.27	0.73	0.79	0.28	0.50
0.25	0.75	0.84	0.27	0.50
0.26	0.74	0.84	0.28	0.50
0.25	0.74	0.82	0.27	0.50
0.26	0.76	0.83	0.27	0.50
0.25	0.76	0.85	0.27	0.50
0.26	0.76	0.85	0.27	0.50
0.25	0.76	0.85	0.27	0.50
0.27	0.72	0.76	0.28	0.50
0.25	0.73	0.80	0.27	0.50
0.26	0.72	0.82	0.28	0.50
0.25	0.73	0.79	0.27	0.50
0.25	0.74	0.80	0.27	0.50
0.25	0.74	0.80	0.27	0.50
0.25	0.74	0.82	0.27	0.50
0.24	0.74	0.83	0.27	0.50
0.27	0.74	0.84	0.27	0.50
0.25	0.76	0.84	0.27	0.50
0.26	0.73	0.81	0.27	0.50
0.26	0.75	0.84	0.27	0.50
0.26	0.74	0.84	0.27	0.50
0.26	0.75	0.82	0.27	0.50
0.26	0.76	0.83	0.27	0.50
0.26	0.76	0.84	0.27	0.50
0.27	0.76	0.84	0.27	0.50
0.25	0.76	0.84	0.27	0.50
0.26	0.72	0.78	0.27	0.50
0.26	0.74	0.81	0.27	0.50
0.26	0.72	0.81	0.27	0.50
0.26	0.72	0.79	0.27	0.50

0.62	0.45	0.46	0.68	0.85
0.60	0.44	0.48	0.66	0.85
0.61	0.45	0.46	0.68	0.85
0.66	0.33	0.34	0.72	0.85
0.61	0.44	0.43	0.66	0.85
0.64	0.36	0.37	0.69	0.85
0.62	0.40	0.40	0.69	0.85
0.63	0.39	0.38	0.69	0.85
0.61	0.43	0.43	0.68	0.85
0.60	0.42	0.44	0.66	0.85
0.61	0.44	0.44	0.68	0.85
0.67	0.35	0.43	0.71	0.90
0.65	0.45	0.43	0.70	0.90
0.72	0.29	0.31	0.78	0.90
0.66	0.39	0.43	0.71	0.90
0.70	0.31	0.36	0.75	0.90
0.68	0.37	0.38	0.74	0.90
0.69	0.33	0.37	0.74	0.90
0.67	0.37	0.39	0.72	0.90
0.67	0.36	0.42	0.71	0.90
0.68	0.37	0.39	0.72	0.90
0.72	0.27	0.27	0.78	0.90
0.66	0.37	0.39	0.71	0.90
0.69	0.30	0.32	0.75	0.90
0.68	0.34	0.34	0.74	0.90
0.68	0.31	0.33	0.74	0.90
0.67	0.36	0.35	0.72	0.90
0.67	0.35	0.39	0.71	0.90
0.67	0.36	0.36	0.72	0.90
0.72	0.29	0.41	0.76	0.95
0.70	0.38	0.37	0.75	0.95
0.77	0.23	0.26	0.84	0.95
0.71	0.34	0.39	0.75	0.95
0.75	0.26	0.32	0.80	0.95
0.73	0.31	0.32	0.79	0.95
0.74	0.27	0.32	0.79	0.95
0.72	0.31	0.34	0.77	0.95
0.73	0.30	0.38	0.76	0.95
0.73	0.31	0.33	0.77	0.95
0.77	0.22	0.22	0.84	0.95
0.71	0.33	0.35	0.75	0.95
0.75	0.24	0.30	0.80	0.95
0.73	0.29	0.28	0.79	0.95

0.26	0.74	0.80	0.27	0.50
0.25	0.74	0.82	0.27	0.50
0.26	0.73	0.80	0.27	0.50
0.25	0.75	0.80	0.27	0.50
0.27	0.74	0.83	0.26	0.50
0.26	0.76	0.84	0.27	0.50
0.26	0.74	0.82	0.27	0.50
0.27	0.75	0.83	0.27	0.50
0.26	0.74	0.84	0.27	0.50
0.26	0.75	0.83	0.26	0.50
0.26	0.76	0.83	0.26	0.50
0.26	0.76	0.84	0.26	0.50
0.27	0.76	0.84	0.26	0.50
0.26	0.76	0.84	0.26	0.50
0.25	0.72	0.79	0.27	0.50
0.27	0.74	0.80	0.27	0.50
0.26	0.72	0.80	0.27	0.50
0.26	0.73	0.80	0.26	0.50
0.26	0.74	0.79	0.26	0.50
0.26	0.74	0.80	0.26	0.50
0.27	0.74	0.80	0.26	0.50
0.26	0.74	0.81	0.26	0.50
0.28	0.75	0.82	0.26	0.50
0.27	0.77	0.83	0.27	0.50
0.25	0.75	0.84	0.26	0.50
0.28	0.76	0.83	0.26	0.50
0.26	0.75	0.83	0.26	0.50
0.27	0.76	0.83	0.26	0.50
0.27	0.76	0.83	0.26	0.50
0.27	0.76	0.83	0.26	0.50
0.28	0.76	0.83	0.26	0.50
0.27	0.76	0.83	0.26	0.50
0.25	0.73	0.80	0.26	0.50
0.27	0.73	0.79	0.26	0.50
0.26	0.73	0.79	0.26	0.50
0.26	0.74	0.80	0.26	0.50
0.26	0.74	0.79	0.26	0.50
0.27	0.74	0.80	0.26	0.50
0.28	0.74	0.79	0.26	0.50
0.27	0.74	0.80	0.26	0.50
0.28	0.75	0.82	0.26	0.50
0.28	0.77	0.83	0.27	0.50
0.25	0.75	0.85	0.25	0.50

0.74	0.25	0.29	0.79	0.95
0.72	0.29	0.31	0.77	0.95
0.72	0.28	0.33	0.76	0.95
0.73	0.29	0.31	0.77	0.95
0.77	0.24	0.39	0.79	1.00
0.75	0.32	0.30	0.79	1.00
0.81	0.19	0.23	0.89	1.00
0.76	0.29	0.35	0.79	1.00
0.79	0.22	0.30	0.84	1.00
0.78	0.26	0.26	0.84	1.00
0.79	0.22	0.28	0.84	1.00
0.77	0.25	0.29	0.81	1.00
0.78	0.24	0.34	0.79	1.00
0.78	0.25	0.29	0.81	1.00
0.81	0.17	0.20	0.89	1.00
0.76	0.27	0.33	0.79	1.00
0.79	0.20	0.26	0.84	1.00
0.78	0.25	0.24	0.84	1.00
0.79	0.20	0.25	0.84	1.00
0.77	0.23	0.25	0.81	1.00
0.78	0.23	0.31	0.79	1.00
0.78	0.22	0.25	0.81	1.00
0.82	0.19	0.37	0.82	1.00
0.80	0.27	0.24	0.83	1.00
0.85	0.15	0.21	0.92	1.00
0.81	0.23	0.31	0.82	1.00
0.83	0.18	0.28	0.87	1.00
0.83	0.21	0.22	0.88	1.00
0.83	0.17	0.25	0.88	1.00
0.82	0.20	0.25	0.85	1.00
0.83	0.19	0.32	0.82	1.00
0.83	0.20	0.25	0.85	1.00
0.85	0.14	0.19	0.92	1.00
0.80	0.22	0.29	0.82	1.00
0.83	0.16	0.25	0.87	1.00
0.83	0.19	0.19	0.88	1.00
0.83	0.16	0.22	0.88	1.00
0.82	0.19	0.21	0.85	1.00
0.83	0.18	0.29	0.82	1.00
0.83	0.19	0.22	0.85	1.00
0.86	0.15	0.36	0.84	1.00
0.85	0.21	0.18	0.86	1.00
0.88	0.12	0.20	0.95	1.00

0.28	0.76	0.82	0.27	0.50
0.27	0.75	0.82	0.26	0.50
0.27	0.76	0.83	0.27	0.50
0.27	0.76	0.82	0.26	0.50
0.28	0.76	0.82	0.27	0.50
0.29	0.76	0.82	0.26	0.50
0.28	0.76	0.82	0.27	0.50
0.24	0.73	0.82	0.25	0.50
0.28	0.74	0.79	0.27	0.50
0.26	0.74	0.80	0.26	0.50
0.27	0.75	0.80	0.26	0.50
0.27	0.75	0.78	0.26	0.50
0.28	0.75	0.79	0.27	0.50
0.28	0.74	0.78	0.26	0.50
0.28	0.74	0.79	0.27	0.50
0.29	0.75	0.81	0.26	0.50
0.29	0.77	0.82	0.28	0.50
0.25	0.76	0.85	0.26	0.50
0.29	0.76	0.82	0.27	0.50
0.27	0.75	0.81	0.26	0.50
0.28	0.76	0.83	0.27	0.50
0.27	0.75	0.82	0.27	0.50
0.29	0.76	0.81	0.27	0.50
0.29	0.75	0.81	0.27	0.50
0.29	0.76	0.81	0.27	0.50
0.25	0.74	0.81	0.26	0.50
0.29	0.75	0.77	0.27	0.50
0.27	0.74	0.77	0.26	0.50
0.27	0.74	0.80	0.27	0.50
0.27	0.74	0.78	0.27	0.50
0.29	0.74	0.79	0.27	0.50
0.29	0.74	0.79	0.27	0.50
0.29	0.75	0.78	0.27	0.50
0.30	0.75	0.80	0.28	0.50
0.30	0.78	0.82	0.29	0.50
0.26	0.76	0.84	0.27	0.50
0.30	0.76	0.81	0.28	0.50
0.28	0.76	0.80	0.27	0.50
0.28	0.77	0.83	0.28	0.50
0.28	0.75	0.81	0.28	0.50
0.29	0.76	0.81	0.29	0.50
0.30	0.75	0.80	0.28	0.50
0.30	0.76	0.81	0.28	0.50

0.86	0.18	0.27	0.85	1.00
0.87	0.13	0.27	0.90	1.00
0.87	0.16	0.18	0.91	1.00
0.87	0.14	0.23	0.91	1.00
0.86	0.16	0.22	0.88	1.00
0.87	0.15	0.30	0.84	1.00
0.87	0.16	0.22	0.88	1.00
0.88	0.10	0.17	0.95	1.00
0.85	0.16	0.23	0.85	1.00
0.87	0.12	0.25	0.90	1.00
0.87	0.15	0.14	0.91	1.00
0.87	0.12	0.19	0.91	1.00
0.86	0.15	0.18	0.88	1.00
0.87	0.14	0.28	0.84	1.00
0.87	0.15	0.18	0.88	1.00
0.91	0.10	0.34	0.85	1.00
0.90	0.16	0.12	0.89	1.00
0.90	0.09	0.19	0.97	1.00
0.90	0.13	0.23	0.87	1.00
0.91	0.09	0.27	0.91	1.00
0.90	0.12	0.15	0.94	1.00
0.91	0.11	0.21	0.93	1.00
0.91	0.13	0.19	0.91	1.00
0.91	0.12	0.29	0.86	1.00
0.90	0.13	0.19	0.91	1.00
0.90	0.07	0.16	0.97	1.00
0.90	0.10	0.19	0.87	1.00
0.90	0.08	0.23	0.91	1.00
0.90	0.09	0.12	0.94	1.00
0.90	0.09	0.18	0.93	1.00
0.90	0.10	0.17	0.91	1.00
0.91	0.10	0.24	0.86	1.00
0.90	0.11	0.16	0.91	1.00
0.95	0.06	0.33	0.86	1.00
0.95	0.10	0.06	0.91	1.00
0.92	0.06	0.19	0.99	1.00
0.95	0.08	0.19	0.89	1.00
0.94	0.06	0.27	0.92	1.00
0.94	0.08	0.13	0.95	1.00
0.94	0.08	0.20	0.94	1.00
0.94	0.09	0.17	0.92	1.00
0.95	0.08	0.27	0.88	1.00
0.94	0.09	0.17	0.92	1.00

0.25	0.74	0.82	0.27	0.50
0.30	0.74	0.77	0.28	0.50
0.28	0.74	0.77	0.27	0.50
0.28	0.74	0.79	0.28	0.50
0.28	0.73	0.79	0.28	0.50
0.29	0.73	0.78	0.29	0.50
0.30	0.73	0.77	0.28	0.50
0.30	0.74	0.78	0.28	0.50
0.30	0.75	0.79	0.30	0.50
0.31	0.78	0.81	0.31	0.50
0.27	0.76	0.82	0.29	0.50
0.31	0.76	0.81	0.30	0.50
0.29	0.76	0.79	0.30	0.50
0.29	0.77	0.82	0.30	0.50
0.29	0.74	0.80	0.30	0.50
0.30	0.76	0.80	0.30	0.50
0.30	0.75	0.80	0.30	0.50
0.31	0.76	0.80	0.30	0.50
0.27	0.75	0.77	0.29	0.50
0.31	0.75	0.78	0.30	0.50
0.29	0.74	0.75	0.30	0.50
0.29	0.75	0.78	0.30	0.50
0.29	0.73	0.76	0.30	0.50
0.30	0.74	0.76	0.30	0.50
0.30	0.73	0.75	0.30	0.50
0.31	0.74	0.77	0.30	0.50

0.92	0.04	0.17	0.99	1.00
0.95	0.06	0.17	0.89	1.00
0.94	0.04	0.22	0.92	1.00
0.93	0.06	0.10	0.95	1.00
0.93	0.06	0.17	0.94	1.00
0.94	0.08	0.13	0.92	1.00
0.94	0.06	0.24	0.88	1.00
0.93	0.07	0.15	0.92	1.00
1.00	0.02	0.31	0.87	1.00
1.00	0.05	0.00	0.93	1.00
0.94	0.03	0.19	1.00	1.00
1.00	0.04	0.15	0.90	1.00
0.97	0.02	0.26	0.93	1.00
0.96	0.04	0.11	0.96	1.00
0.96	0.05	0.19	0.94	1.00
0.98	0.06	0.14	0.93	1.00
0.98	0.05	0.26	0.89	1.00
0.97	0.06	0.14	0.93	1.00
0.94	0.01	0.16	1.00	1.00
1.00	0.02	0.13	0.90	1.00
0.97	0.00	0.23	0.93	1.00
0.96	0.03	0.07	0.96	1.00
0.96	0.04	0.15	0.94	1.00
0.98	0.04	0.10	0.93	1.00
0.98	0.02	0.23	0.89	1.00
0.97	0.04	0.11	0.93	1.00

Table 4 Conventional setup plant parameters (Plant A)

Day	No. of Leaf	Height (mm)	Diameter (mm)	Canopy Area(mm^2)	Lighting (umol/m^/s)
0	0	0.00	0.00	0	indoor
5	2	19.02	10.25	105.06	indoor
10	2	25.88	16.44	270.14	indoor
15	3	32.36	25.16	632.92	indoor
20	4	37.41	32.54	1058.97	50.38
25	4	46.91	42.43	1800.422249	41.96
30	5	56.80	55.02	3027.729921	55.48
35	6	68.77	70.57	4980.250873	55.30
40	7	83.79	91.74	8416.537343	48.98
45	7	99.10	115.61	13365.46097	52.81
50	13	122.78	146.01	21319.93138	45.76
55	15	149.12	185.38	34364.24644	60.98

Table 5 Conventional setup plant parameters (Plant B)

Day	No. of Leaf	Height (mm)	Diameter (mm)	Canopy Area(mm^2)	Lighting (umol/m^/s)
0	0	0.00	0.00	0	indoor
5	2	20.35	13.16	173.22	indoor
10	3	26.87	23.48	551.35	indoor
15	4	32.43	30.53	932.22	indoor
20	4	40.59	40.38	1630.86	52.39
25	4	50.02	53.16	2825.472126	40.87
30	5	61.76	69.52	4832.768174	51.10
35	6	74.26	90.18	8132.125433	51.36
40	6	89.00	115.37	13309.15809	52.17
45	7	109.82	149.41	22322.04406	53.32
50	13	135.61	189.93	36074.24843	40.44
55	16	166.63	239.03	57133.88379	64.35

Table 6 Conventional setup plant parameters (Plant C)

Day	No. of Leaf	Height (mm)	Diameter (mm)	Canopy Area(mm^2)	Lighting (umol/m^/s)
0	0	0.00	0.00	0	indoor
5	2	22.31	13.51	182.44	indoor
10	3	30.35	25.80	665.65	indoor
15	4	36.90	33.59	1128.10	indoor
20	4	45.96	47.30	2237.54	49.76
25	4	56.62	59.71	3565.760643	42.12
30	5	69.60	77.69	6035.563391	51.52
35	7	84.79	100.20	10040.24368	55.41
40	7	101.57	130.57	17048.52659	51.10
45	8	122.69	171.26	29329.89055	54.96
50	13	151.70	212.62	45205.98979	43.74
55	17	186.36	276.03	76192.62673	60.23

Table 7 Conventional setup plant parameters (Plant D)

Day	No. of Leaf	Height (mm)	Diameter (mm)	Canopy Area(mm^2)	Lighting (umol/m^/s)
0	0	0.00	0.00	0	indoor
5	2	18.97	10.18	103.5424464	indoor
10	2	25.23	16.77	281.3427688	indoor
15	3	30.54	24.86	618.0588488	indoor
20	4	38.01	35.07	1230.108415	51.28
25	4	47.27	44.34	1966.233325	43.13
30	6	57.71	57.98	3361.445401	52.09
35	7	70.73	74.27	5516.711312	53.25
40	8	84.17	96.05	9225.296084	50.86
45	8	97.64	123.90	15351.12942	54.64
50	12	120.86	158.52	25127.3071	44.41
55	17	145.51	202.96	41193.30163	63.08

Table 8 Controlled Lighting setup plant parameters (Plant A)

Day	No. of Leaf	Height (mm)	Diameter (mm)	Canopy Area(mm^2)	Lighting (umol/m^/s)
0	0	0.00	0.00	0	indoor
5	2	19.30	10.04	100.80	indoor
10	2	24.83	15.93	253.77	indoor
15	2	31.15	25.18	634.20	indoor
20	3	39.10	33.75	1138.78	44.87
25	3	48.72	45.37	2058.293562	42.50
30	4	61.76	62.24	3874.258562	40.40
35	5	74.41	82.97	6884.8047	38.55
40	6	91.89	112.82	12727.99304	36.26
45	7	115.31	148.47	22043.71334	34.23
50	10	143.94	201.15	40461.58505	32.47
55	12	179.66	268.96	72339.40358	30.87

Table 9 Controlled Lighting setup plant parameters (Plant B)

Day	No. of Leaf	Height (mm)	Diameter (mm)	Canopy Area(mm^2)	Lighting (umol/m^/s)
0	0	0.00	0.00	0	indoor
5	2	20.10	12.90	166.41	indoor
10	3	25.81	19.95	397.85	indoor
15	3	33.73	30.56	934.16	indoor
20	4	42.30	41.75	1743.22	45.84
25	4	53.65	56.14	3151.767285	43.61
30	5	68.12	74.90	5609.647221	41.40
35	5	87.17	101.48	10297.87764	39.77
40	6	109.32	135.34	18318.14723	37.43
45	7	133.87	182.72	33388.17201	35.39
50	9	166.09	246.19	60611.22914	33.52
55	13	206.13	332.90	110824.6058	31.73

Table 10 Controlled Lighting setup plant parameters (Plant C)

Day	No. of Leaf	Height (mm)	Diameter (mm)	Canopy Area(mm^2)	Lighting (umol/m^/s)
0	0	0.00	0.00	0	indoor
5	2	22.60	13.80	190.44	indoor
10	2	29.02	21.76	473.68	indoor
15	3	38.12	33.62	1130.45	indoor
20	4	47.90	45.74	2092.19	44.93
25	4	58.67	60.84	3700.949597	42.88
30	5	73.73	84.02	7060.17643	40.18
35	6	88.97	110.16	12134.23329	38.48
40	7	111.75	148.39	22020.2048	37.74
45	8	139.14	193.25	37344.86222	36.45
50	9	175.14	269.82	72802.99864	33.62
55	13	217.85	366.74	134498.0855	32.45

Table 11 Controlled Lighting setup plant parameters (Plant D)

Day	No. of Leaf	Height (mm)	Diameter (mm)	Canopy Area(mm^2)	Lighting (umol/m^/s)
0	0	0.00	0.00	0	indoor
5	2	19.30	10.40	108.16	indoor
10	2	24.23	15.64	244.69	indoor
15	3	31.65	24.89	619.34	indoor
20	3	39.70	33.75	1138.96	44.23
25	4	48.93	45.21	2043.83	42.28
30	6	61.32	61.49	3781.50	39.87
35	6	76.36	83.13	6910.75	38.19
40	7	94.74	112.00	12543.60	36.00
45	8	115.97	155.53	24188.45	33.87
50	9	145.22	215.86	46594.50	32.05
55	14	183.30	286.68	82183.02	30.54

APPENDIX B

BILL OF MATERIALS

Item	Unit	Quantity	Unit Cost	Amount
Raspberry Pi	pcs.	1	2400	2400
SD Card	pcs.	1	500	500
Raspberry Pi Power Supply	pcs.	1	400	400
Raspberry Pi Case	pcs.	1	350	350
HDMA - VGA Cable	pcs.	1	250	250
Logitech C922 Webcam	pcs.	1	5050	5050
Digital Vernier Caliper	pcs.	2	600	1200
Keyboard	pcs.	1	250	250
Neopixel LED Strip RGB 60LEDs/M	roll	2	1700	3400
DS3231 RTC High Precision Real-time Clock	pcs.	1	150	150
Real-time Clock	pcs.	2	189	378
Real-time Clock Battery	pcs.	2	40	80
Seed Tray	pcs.	2	40	80
Grand Rapid Seed	pcs.	7	40	280
Soil	sack	1	60	60
SWBR 061 10m.	pcs.	2	65	130
H313	pcs.	2	36	72
Rivet 1/8x1/2	pcs.	60	0.5	30
Drill bit 1/4	pcs.	1	120	120
Nail #1	pack	1	25	25
Plywood 3x4	pcs.	1	1200	1200
Nail #3	kilos	1/2	80	40
Blind Rivet 18/58	pcs.	60	0.5	30
Door Hinge	set	2	20	40
Doritier	pcs.	1	70	70
Door Handle	pcs.	2	15	30
Stikwel	pcs.	1	50	50
catches	pcs.	2	30	60
Skeletal box frame	set	1	1500	1500
2800660000321 Slotted Angle Bar 2.0mm	pcs.	3	179	537
2800660000338 Slotted Angle Bar 2.0mm	pcs.	2	223	446
Metro	pcs.	1	85	85
Bolt 8x65	pcs.	80	4.75	380
Wallmount 13-23 lcdt	pcs.	1	299	299
Flat 1/8 x 3/4 x16'	pcs.	1	145	145
Blind Rivets 1/8x5/8	pcs.	100	0.5	50
Noble Wiring Devices	pcs.	1	469.75	469.75
10L Insulation	meter	8	75	600
Slotte Angle 12ft.	pcs.	3	313	939
Trans Head	pcs.	40	2.4	96
Soil	sack	1	60	60
			Total:	17615

APPENDIX C

PROGRAM CODES

FIS_HEADER.H

```
//*********************************************************************
*
// Matlab .fis to arduino C converter v2.0.1.25122016
// - Karthik Nadig, USA
// Please report bugs to: karthiknadig@gmail.com
//*********************************************************************
*
#define FIS_TYPE float
#define FIS_RESOLUSION 101
#define FIS_MIN -3.4028235E+38
#define FIS_MAX 3.4028235E+38
typedef FIS_TYPE(*_FIS_MF)(FIS_TYPE, FIS_TYPE*);
typedef FIS_TYPE(*_FIS_ARR_OP)(FIS_TYPE, FIS_TYPE);
typedef FIS_TYPE(*_FIS_ARR)(FIS_TYPE*, int, _FIS_ARR_OP);
```

ARDUINO MAIN SCRIPT

```
//************************************************************************
// ANFIS
//************************************************************************

#include "fis_header.h"

const int fis_gcI = 4;
const int fis_gcO = 1;
const int fis_gcR = 81;

FIS_TYPE g_fisInput[fis_gcI];
FIS_TYPE g_fisOutput[fis_gcO];


//************************************************************************
// LIGHTING NEOPIXEL
//************************************************************************
#include <Adafruit_NeoPixel.h>

#define NUM_LEDS 180

#define LED_PIN1 31
#define LED_PIN2 33
#define LED_PIN3 35
#define LED_PIN4 37

Adafruit_NeoPixel strip_a = Adafruit_NeoPixel(NUM_LEDS, LED_PIN1);
Adafruit_NeoPixel strip_b = Adafruit_NeoPixel(NUM_LEDS, LED_PIN2);
Adafruit_NeoPixel strip_c = Adafruit_NeoPixel(NUM_LEDS, LED_PIN3);
Adafruit_NeoPixel strip_d = Adafruit_NeoPixel(NUM_LEDS, LED_PIN4);

int red, blue, green,white;

//************************************************************************
// REAL TIME CLOCK DS3231
//************************************************************************
#include <DS3231.h>

DS3231  rtc(SDA, SCL);
Time t;


int rtc_hr;
int rtc_min;
int rtc_sec;

//************************************************************************
//MISC
//************************************************************************
float y,cb,cr,pcount;
boolean trigger,timer;
String rqstat;

//************************************************************************
```

```
//SETUP
//**********************************************************************

void setup()
{
  Serial.begin(9600);
  strip_a.begin();
  strip_b.begin();
  strip_c.begin();
  strip_d.begin();

  strip_a.show();
  strip_b.show();
  strip_c.show();
  strip_d.show();

  rtc.begin();
//SET TIME(Remove Comment)
//rtc.setDOW(TUESDAY);
//rtc.setTime(17, 03, 0);
//rtc.setDate(10, 02, 2018);

}


//**********************************************************************
//LOOP
//**********************************************************************
void loop()
{
  rtctime();
  rqstat = Serial.readString();

//  if(trigger == 1)
//  {
//    Serial.println("START");
//  }

  if(rqstat == "CAPTURE")
  {
    capture();
  }

  if(rqstat == "INPUT")
  {
    input();
    anfis();
  }

  if(rqstat == "OUTPUT")
  {
    output();
  }


  if(timer == 1)
```

```
 {

 for(int i = 0; i<NUM_LEDS ;i++)
   {
   strip_a.setPixelColor(i, red, 0, blue);
   strip_b.setPixelColor(i, red, 0, blue);
   strip_c.setPixelColor(i, red, 0, blue);
   strip_d.setPixelColor(i, red, 0, blue);
   }

   strip_a.show();
   strip_b.show();
   strip_c.show();
   strip_d.show();
 }

 else if (timer == 0)
 {
   for(int i = 0; i<NUM_LEDS;i++)
   {
   strip_a.setPixelColor(i, 0, 0, 0);
   strip_b.setPixelColor(i, 0, 0, 0);
   strip_c.setPixelColor(i, 0, 0, 0);
   strip_d.setPixelColor(i, 0, 0, 0);
   }

   strip_a.show();
   strip_b.show();
   strip_c.show();
   strip_d.show();

 }



}

//*************************************************************************
// CAPTURE IMAGE
//*************************************************************************
void capture()
{

  for(int i = 0; i<NUM_LEDS;i++)
 {
 strip_a.setPixelColor(i, 255, 255, 255);
 strip_b.setPixelColor(i, 255, 255, 255);
 strip_c.setPixelColor(i, 255, 255, 255);
 strip_d.setPixelColor(i, 255, 255, 255);

 strip_a.show();
 strip_b.show();
 strip_c.show();
 strip_d.show();
```

```
  }
  delay(5000);
}


//**********************************************************************
// ANFIS INPUT
//**********************************************************************
void input()
{
   delay(50);
   y = Serial.parseFloat();
   delay(50);

   cb = Serial.parseFloat();
   delay(50);

   cr = Serial.parseFloat();
   delay(50);

   pcount = Serial.parseFloat();
   delay(50);

}

//**********************************************************************
// ANFIS
//**********************************************************************

void anfis()
{
   g_fisInput[0] = y;
   g_fisInput[1] = cb;
   g_fisInput[2] = cr;
   g_fisInput[3] = pcount;
   g_fisOutput[0] = 0;
   fis_evaluate();
   red = map(g_fisOutput[0], 0, 100, 0, 255);
   blue = 255 - red;
}

//**********************************************************************
// OUTPUT
//**********************************************************************

void output()
{
   delay(1000);
  // Serial.println("READY");
   Serial.print(rtc_hr);
   Serial.print(":");
   Serial.print(rtc_min);
   Serial.print(":");
   Serial.println(rtc_sec);

   delay(1000);
```

```
  if(timer == 1)
  {
   Serial.println("LED ON");
  }

  else
  {
   Serial.println("LED OFF");
  }

  delay(1000);

  Serial.print("[");
  Serial.print(red);
  Serial.print(":");
  Serial.print(green);
  Serial.print(":");
  Serial.print(blue);
  Serial.println("]");
  delay(1000);
}


//************************************************************************
// RTC
//************************************************************************

void rtctime()
{

 t = rtc.getTime();
 rtc_hr = t.hour;
 rtc_min = t.min;
 rtc_sec = t.sec;


 if (rtc_hr == 7 || rtc_hr == 13 && rtc_sec < 3)
 {
  trigger = 1;
 }

 else
 {
  trigger = 0;
 }


 if (rtc_hr > 6 && rtc_hr < 24)
 {
  timer = 1;

 }

 else
 {
```

```
    timer = 0;
  }

}

//***********************************************************************
// Support functions for Fuzzy Inference System
//***********************************************************************
// Gaussian Member Function
FIS_TYPE fis_gaussmf(FIS_TYPE x, FIS_TYPE* p)
{
    FIS_TYPE s = p[0], c = p[1];
    FIS_TYPE t = (x - c) / s;
    return exp(-(t * t) / 2);
}

FIS_TYPE fis_prod(FIS_TYPE a, FIS_TYPE b)
{
    return (a * b);
}

FIS_TYPE fis_probor(FIS_TYPE a, FIS_TYPE b)
{
    return (a + b - (a * b));
}

FIS_TYPE fis_sum(FIS_TYPE a, FIS_TYPE b)
{
    return (a + b);
}

FIS_TYPE fis_array_operation(FIS_TYPE *array, int size, _FIS_ARR_OP pfnOp)
{
    int i;
    FIS_TYPE ret = 0;

    if (size == 0) return ret;
    if (size == 1) return array[0];

    ret = array[0];
    for (i = 1; i < size; i++)
    {
        ret = (*pfnOp)(ret, array[i]);
    }

    return ret;
}


//***********************************************************************
// Data for Fuzzy Inference System
//***********************************************************************
// Pointers to the implementations of member functions
_FIS_MF fis_gMF[] =
{
    fis_gaussmf
```

```
};

// Count of member function for each Input
int fis_gIMFCount[] = { 3, 3, 3, 3 };

// Count of member function for each Output
int fis_gOMFCount[] = { 81 };

// Coefficients for the Input Member Functions
FIS_TYPE fis_gMFI0Coeff1[] = { 7.42492051325072, 186.69313766753 };
FIS_TYPE fis_gMFI0Coeff2[] = { 7.40500982597538, 204.123672321235 };
FIS_TYPE fis_gMFI0Coeff3[] = { 7.40458607812405, 221.565576418035 };
FIS_TYPE* fis_gMFI0Coeff[] = { fis_gMFI0Coeff1, fis_gMFI0Coeff2, fis_gMFI0Coeff3 };
FIS_TYPE fis_gMFI1Coeff1[] = { 0.467465697631379, 126.621815050364 };
FIS_TYPE fis_gMFI1Coeff2[] = { 0.510155137462474, 127.106234771349 };
FIS_TYPE fis_gMFI1Coeff3[] = { 0.134535553862969, 127.979419543856 };
FIS_TYPE* fis_gMFI1Coeff[] = { fis_gMFI1Coeff1, fis_gMFI1Coeff2, fis_gMFI1Coeff3 };
FIS_TYPE fis_gMFI2Coeff1[] = { 0.0910510992542481, 127.852822741108 };
FIS_TYPE fis_gMFI2Coeff2[] = { 0.320788165147677, 128.43525011783 };
FIS_TYPE fis_gMFI2Coeff3[] = { 0.255853990139131, 128.691691476054 };
FIS_TYPE* fis_gMFI2Coeff[] = { fis_gMFI2Coeff1, fis_gMFI2Coeff2, fis_gMFI2Coeff3 };
FIS_TYPE fis_gMFI3Coeff1[] = { 10086.4395248557, 1291.49999419336 };
FIS_TYPE fis_gMFI3Coeff2[] = { 10086.4395116701, 25043.2500079733 };
FIS_TYPE fis_gMFI3Coeff3[] = { 10086.4395355159, 48794.9999996688 };
FIS_TYPE* fis_gMFI3Coeff[] = { fis_gMFI3Coeff1, fis_gMFI3Coeff2, fis_gMFI3Coeff3 };
FIS_TYPE** fis_gMFICoeff[] = { fis_gMFI0Coeff, fis_gMFI1Coeff, fis_gMFI2Coeff, fis_gMFI3Coeff };

// Coefficients for the Output Member Functions
FIS_TYPE fis_gMFO0Coeff1[] = { 0, 0, 0, 0, -8.11363843222922 };
FIS_TYPE fis_gMFO0Coeff2[] = { 0, 0, 0, 0, -1.55212218171144 };
FIS_TYPE fis_gMFO0Coeff3[] = { 0, 0, 0, 0, -0.00121910753828649 };
FIS_TYPE fis_gMFO0Coeff4[] = { 0, 0, 0, 0, -122.340894710048 };
FIS_TYPE fis_gMFO0Coeff5[] = { 0, 0, 0, 0, -2.85750201336134 };
FIS_TYPE fis_gMFO0Coeff6[] = { 0, 0, 0, 0, 97.6769176667602 };
FIS_TYPE fis_gMFO0Coeff7[] = { 0, 0, 0, 0, -47.5814424690061 };
FIS_TYPE fis_gMFO0Coeff8[] = { 0, 0, 0, 0, 44.9637495746751 };
FIS_TYPE fis_gMFO0Coeff9[] = { 0, 0, 0, 0, 73.2464456194109 };
FIS_TYPE fis_gMFO0Coeff10[] = { 0, 0, 0, 0, -64.7649543561018 };
FIS_TYPE fis_gMFO0Coeff11[] = { 0, 0, 0, 0, -15.4038232951493 };
FIS_TYPE fis_gMFO0Coeff12[] = { 0, 0, 0, 0, -0.0120416577544484 };
FIS_TYPE fis_gMFO0Coeff13[] = { 0, 0, 0, 0, -183.618217764049 };
FIS_TYPE fis_gMFO0Coeff14[] = { 0, 0, 0, 0, 108.86892359307 };
FIS_TYPE fis_gMFO0Coeff15[] = { 0, 0, 0, 0, -56.4560035224995 };
FIS_TYPE fis_gMFO0Coeff16[] = { 0, 0, 0, 0, 137.733297213817 };
FIS_TYPE fis_gMFO0Coeff17[] = { 0, 0, 0, 0, 231.447670938031 };
FIS_TYPE fis_gMFO0Coeff18[] = { 0, 0, 0, 0, 97.6707375931137 };
FIS_TYPE fis_gMFO0Coeff19[] = { 0, 0, 0, 0, -27.5755706877018 };
FIS_TYPE fis_gMFO0Coeff20[] = { 0, 0, 0, 0, -28.698859602851 };
FIS_TYPE fis_gMFO0Coeff21[] = { 0, 0, 0, 0, -0.0183467826524075 };
FIS_TYPE fis_gMFO0Coeff22[] = { 0, 0, 0, 0, 35.9456722006186 };
FIS_TYPE fis_gMFO0Coeff23[] = { 0, 0, 0, 0, 541.423450769224 };
FIS_TYPE fis_gMFO0Coeff24[] = { 0, 0, 0, 0, 0.686317113445857 };
FIS_TYPE fis_gMFO0Coeff25[] = { 0, 0, 0, 0, 512.411391061156 };
FIS_TYPE fis_gMFO0Coeff26[] = { 0, 0, 0, 0, 224.356943230896 };
FIS_TYPE fis_gMFO0Coeff27[] = { 0, 0, 0, 0, 0.322512657693565 };
FIS_TYPE fis_gMFO0Coeff28[] = { 0, 0, 0, 0, 68.8864013567759 };
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FIS_TYPE fis_gMFO0Coeff29[] = { 0, 0, 0, 0, 16.8373255505705 };
FIS_TYPE fis_gMFO0Coeff30[] = { 0, 0, 0, 0, 0.0134620197949238 };
FIS_TYPE fis_gMFO0Coeff31[] = { 0, 0, 0, 0, 2518.78671926893 };
FIS_TYPE fis_gMFO0Coeff32[] = { 0, 0, 0, 0, -548.343204406797 };
FIS_TYPE fis_gMFO0Coeff33[] = { 0, 0, 0, 0, 250.001932242103 };
FIS_TYPE fis_gMFO0Coeff34[] = { 0, 0, 0, 0, 289.717903100243 };
FIS_TYPE fis_gMFO0Coeff35[] = { 0, 0, 0, 0, -260.50993922716 };
FIS_TYPE fis_gMFO0Coeff36[] = { 0, 0, 0, 0, -42.5013193418029 };
FIS_TYPE fis_gMFO0Coeff37[] = { 0, 0, 0, 0, 786.933404162219 };
FIS_TYPE fis_gMFO0Coeff38[] = { 0, 0, 0, 0, 155.51345762956 };
FIS_TYPE fis_gMFO0Coeff39[] = { 0, 0, 0, 0, 0.145901450980551 };
FIS_TYPE fis_gMFO0Coeff40[] = { 0, 0, 0, 0, -78.2204950908487 };
FIS_TYPE fis_gMFO0Coeff41[] = { 0, 0, 0, 0, -44.7867914938795 };
FIS_TYPE fis_gMFO0Coeff42[] = { 0, 0, 0, 0, 315.805602265374 };
FIS_TYPE fis_gMFO0Coeff43[] = { 0, 0, 0, 0, -843.783762551459 };
FIS_TYPE fis_gMFO0Coeff44[] = { 0, 0, 0, 0, 721.700114179695 };
FIS_TYPE fis_gMFO0Coeff45[] = { 0, 0, 0, 0, 39.3184847944147 };
FIS_TYPE fis_gMFO0Coeff46[] = { 0, 0, 0, 0, 19.7223635206579 };
FIS_TYPE fis_gMFO0Coeff47[] = { 0, 0, 0, 0, -182.522110016242 };
FIS_TYPE fis_gMFO0Coeff48[] = { 0, 0, 0, 0, 0.133280628800762 };
FIS_TYPE fis_gMFO0Coeff49[] = { 0, 0, 0, 0, -121.866854391649 };
FIS_TYPE fis_gMFO0Coeff50[] = { 0, 0, 0, 0, 699.8985374648 };
FIS_TYPE fis_gMFO0Coeff51[] = { 0, 0, 0, 0, -40.3190322987075 };
FIS_TYPE fis_gMFO0Coeff52[] = { 0, 0, 0, 0, 952.375955509891 };
FIS_TYPE fis_gMFO0Coeff53[] = { 0, 0, 0, 0, -1823.09196410633 };
FIS_TYPE fis_gMFO0Coeff54[] = { 0, 0, 0, 0, -10.7990797703258 };
FIS_TYPE fis_gMFO0Coeff55[] = { 0, 0, 0, 0, -40.1005406320828 };
FIS_TYPE fis_gMFO0Coeff56[] = { 0, 0, 0, 0, 4.96691731828805 };
FIS_TYPE fis_gMFO0Coeff57[] = { 0, 0, 0, 0, 0.0048788989819809 };
FIS_TYPE fis_gMFO0Coeff58[] = { 0, 0, 0, 0, 851.801145224741 };
FIS_TYPE fis_gMFO0Coeff59[] = { 0, 0, 0, 0, 326.854467297204 };
FIS_TYPE fis_gMFO0Coeff60[] = { 0, 0, 0, 0, -2.80613761914719 };
FIS_TYPE fis_gMFO0Coeff61[] = { 0, 0, 0, 0, 84.9211470942961 };
FIS_TYPE fis_gMFO0Coeff62[] = { 0, 0, 0, 0, -386.919913642432 };
FIS_TYPE fis_gMFO0Coeff63[] = { 0, 0, 0, 0, -4.33756208621789 };
FIS_TYPE fis_gMFO0Coeff64[] = { 0, 0, 0, 0, -352.51072651922 };
FIS_TYPE fis_gMFO0Coeff65[] = { 0, 0, 0, 0, 72.1103113966874 };
FIS_TYPE fis_gMFO0Coeff66[] = { 0, 0, 0, 0, 0.0703503007292005 };
FIS_TYPE fis_gMFO0Coeff67[] = { 0, 0, 0, 0, 77.7747957778337 };
FIS_TYPE fis_gMFO0Coeff68[] = { 0, 0, 0, 0, -58.0256213090771 };
FIS_TYPE fis_gMFO0Coeff69[] = { 0, 0, 0, 0, 59.2039562862621 };
FIS_TYPE fis_gMFO0Coeff70[] = { 0, 0, 0, 0, -288.357237210612 };
FIS_TYPE fis_gMFO0Coeff71[] = { 0, 0, 0, 0, 300.634267208643 };
FIS_TYPE fis_gMFO0Coeff72[] = { 0, 0, 0, 0, 8.64310448034013 };
FIS_TYPE fis_gMFO0Coeff73[] = { 0, 0, 0, 0, 123.83741589779 };
FIS_TYPE fis_gMFO0Coeff74[] = { 0, 0, 0, 0, 277.138674307727 };
FIS_TYPE fis_gMFO0Coeff75[] = { 0, 0, 0, 0, 0.239614788261962 };
FIS_TYPE fis_gMFO0Coeff76[] = { 0, 0, 0, 0, -23.9136735228194 };
FIS_TYPE fis_gMFO0Coeff77[] = { 0, 0, 0, 0, 37.8214782178656 };
FIS_TYPE fis_gMFO0Coeff78[] = { 0, 0, 0, 0, -6.11454217892212 };
FIS_TYPE fis_gMFO0Coeff79[] = { 0, 0, 0, 0, 397.631332478227 };
FIS_TYPE fis_gMFO0Coeff80[] = { 0, 0, 0, 0, -305.65860401636 };
FIS_TYPE fis_gMFO0Coeff81[] = { 0, 0, 0, 0, 1.47197700718935 };
FIS_TYPE* fis_gMFO0Coeff[] = { fis_gMFO0Coeff1, fis_gMFO0Coeff2, fis_gMFO0Coeff3,
fis_gMFO0Coeff4, fis_gMFO0Coeff5, fis_gMFO0Coeff6, fis_gMFO0Coeff7, fis_gMFO0Coeff8,
fis_gMFO0Coeff9, fis_gMFO0Coeff10, fis_gMFO0Coeff11, fis_gMFO0Coeff12, fis_gMFO0Coeff13,
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fis_gMFO0Coeff14, fis_gMFO0Coeff15, fis_gMFO0Coeff16, fis_gMFO0Coeff17, fis_gMFO0Coeff18,
fis_gMFO0Coeff19, fis_gMFO0Coeff20, fis_gMFO0Coeff21, fis_gMFO0Coeff22, fis_gMFO0Coeff23,
fis_gMFO0Coeff24, fis_gMFO0Coeff25, fis_gMFO0Coeff26, fis_gMFO0Coeff27, fis_gMFO0Coeff28,
fis_gMFO0Coeff29, fis_gMFO0Coeff30, fis_gMFO0Coeff31, fis_gMFO0Coeff32, fis_gMFO0Coeff33,
fis_gMFO0Coeff34, fis_gMFO0Coeff35, fis_gMFO0Coeff36, fis_gMFO0Coeff37, fis_gMFO0Coeff38,
fis_gMFO0Coeff39, fis_gMFO0Coeff40, fis_gMFO0Coeff41, fis_gMFO0Coeff42, fis_gMFO0Coeff43,
fis_gMFO0Coeff44, fis_gMFO0Coeff45, fis_gMFO0Coeff46, fis_gMFO0Coeff47, fis_gMFO0Coeff48,
fis_gMFO0Coeff49, fis_gMFO0Coeff50, fis_gMFO0Coeff51, fis_gMFO0Coeff52, fis_gMFO0Coeff53,
fis_gMFO0Coeff54, fis_gMFO0Coeff55, fis_gMFO0Coeff56, fis_gMFO0Coeff57, fis_gMFO0Coeff58,
fis_gMFO0Coeff59, fis_gMFO0Coeff60, fis_gMFO0Coeff61, fis_gMFO0Coeff62, fis_gMFO0Coeff63,
fis_gMFO0Coeff64, fis_gMFO0Coeff65, fis_gMFO0Coeff66, fis_gMFO0Coeff67, fis_gMFO0Coeff68,
fis_gMFO0Coeff69, fis_gMFO0Coeff70, fis_gMFO0Coeff71, fis_gMFO0Coeff72, fis_gMFO0Coeff73,
fis_gMFO0Coeff74, fis_gMFO0Coeff75, fis_gMFO0Coeff76, fis_gMFO0Coeff77, fis_gMFO0Coeff78,
fis_gMFO0Coeff79, fis_gMFO0Coeff80, fis_gMFO0Coeff81 };
FIS_TYPE** fis_gMFOCoeff[] = { fis_gMFO0Coeff };

// Input membership function set
int fis_gMFI0[] = { 0, 0, 0 };
int fis_gMFI1[] = { 0, 0, 0 };
int fis_gMFI2[] = { 0, 0, 0 };
int fis_gMFI3[] = { 0, 0, 0 };
int* fis_gMFI[] = { fis_gMFI0, fis_gMFI1, fis_gMFI2, fis_gMFI3};

// Output membership function set

int* fis_gMFO[] = {};

// Rule Weights
FIS_TYPE fis_gRWeight[] = { 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1,
1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1,
1, 1, 1, 1, 1, 1, 1, 1 };

// Rule Type
int fis_gRType[] = { 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1,
1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1,
1, 1, 1, 1 };

// Rule Inputs
int fis_gRI0[] = { 1, 1, 1, 1 };
int fis_gRI1[] = { 1, 1, 1, 2 };
int fis_gRI2[] = { 1, 1, 1, 3 };
int fis_gRI3[] = { 1, 1, 2, 1 };
int fis_gRI4[] = { 1, 1, 2, 2 };
int fis_gRI5[] = { 1, 1, 2, 3 };
int fis_gRI6[] = { 1, 1, 3, 1 };
int fis_gRI7[] = { 1, 1, 3, 2 };
int fis_gRI8[] = { 1, 1, 3, 3 };
int fis_gRI9[] = { 1, 2, 1, 1 };
int fis_gRI10[] = { 1, 2, 1, 2 };
int fis_gRI11[] = { 1, 2, 1, 3 };
int fis_gRI12[] = { 1, 2, 2, 1 };
int fis_gRI13[] = { 1, 2, 2, 2 };
int fis_gRI14[] = { 1, 2, 2, 3 };
int fis_gRI15[] = { 1, 2, 3, 1 };
int fis_gRI16[] = { 1, 2, 3, 2 };
int fis_gRI17[] = { 1, 2, 3, 3 };
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int fis_gRI18[] = { 1, 3, 1, 1 };
int fis_gRI19[] = { 1, 3, 1, 2 };
int fis_gRI20[] = { 1, 3, 1, 3 };
int fis_gRI21[] = { 1, 3, 2, 1 };
int fis_gRI22[] = { 1, 3, 2, 2 };
int fis_gRI23[] = { 1, 3, 2, 3 };
int fis_gRI24[] = { 1, 3, 3, 1 };
int fis_gRI25[] = { 1, 3, 3, 2 };
int fis_gRI26[] = { 1, 3, 3, 3 };
int fis_gRI27[] = { 2, 1, 1, 1 };
int fis_gRI28[] = { 2, 1, 1, 2 };
int fis_gRI29[] = { 2, 1, 1, 3 };
int fis_gRI30[] = { 2, 1, 2, 1 };
int fis_gRI31[] = { 2, 1, 2, 2 };
int fis_gRI32[] = { 2, 1, 2, 3 };
int fis_gRI33[] = { 2, 1, 3, 1 };
int fis_gRI34[] = { 2, 1, 3, 2 };
int fis_gRI35[] = { 2, 1, 3, 3 };
int fis_gRI36[] = { 2, 2, 1, 1 };
int fis_gRI37[] = { 2, 2, 1, 2 };
int fis_gRI38[] = { 2, 2, 1, 3 };
int fis_gRI39[] = { 2, 2, 2, 1 };
int fis_gRI40[] = { 2, 2, 2, 2 };
int fis_gRI41[] = { 2, 2, 2, 3 };
int fis_gRI42[] = { 2, 2, 3, 1 };
int fis_gRI43[] = { 2, 2, 3, 2 };
int fis_gRI44[] = { 2, 2, 3, 3 };
int fis_gRI45[] = { 2, 3, 1, 1 };
int fis_gRI46[] = { 2, 3, 1, 2 };
int fis_gRI47[] = { 2, 3, 1, 3 };
int fis_gRI48[] = { 2, 3, 2, 1 };
int fis_gRI49[] = { 2, 3, 2, 2 };
int fis_gRI50[] = { 2, 3, 2, 3 };
int fis_gRI51[] = { 2, 3, 3, 1 };
int fis_gRI52[] = { 2, 3, 3, 2 };
int fis_gRI53[] = { 2, 3, 3, 3 };
int fis_gRI54[] = { 3, 1, 1, 1 };
int fis_gRI55[] = { 3, 1, 1, 2 };
int fis_gRI56[] = { 3, 1, 1, 3 };
int fis_gRI57[] = { 3, 1, 2, 1 };
int fis_gRI58[] = { 3, 1, 2, 2 };
int fis_gRI59[] = { 3, 1, 2, 3 };
int fis_gRI60[] = { 3, 1, 3, 1 };
int fis_gRI61[] = { 3, 1, 3, 2 };
int fis_gRI62[] = { 3, 1, 3, 3 };
int fis_gRI63[] = { 3, 2, 1, 1 };
int fis_gRI64[] = { 3, 2, 1, 2 };
int fis_gRI65[] = { 3, 2, 1, 3 };
int fis_gRI66[] = { 3, 2, 2, 1 };
int fis_gRI67[] = { 3, 2, 2, 2 };
int fis_gRI68[] = { 3, 2, 2, 3 };
int fis_gRI69[] = { 3, 2, 3, 1 };
int fis_gRI70[] = { 3, 2, 3, 2 };
int fis_gRI71[] = { 3, 2, 3, 3 };
int fis_gRI72[] = { 3, 3, 1, 1 };
int fis_gRI73[] = { 3, 3, 1, 2 };
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int fis_gRI74[] = { 3, 3, 1, 3 };
int fis_gRI75[] = { 3, 3, 2, 1 };
int fis_gRI76[] = { 3, 3, 2, 2 };
int fis_gRI77[] = { 3, 3, 2, 3 };
int fis_gRI78[] = { 3, 3, 3, 1 };
int fis_gRI79[] = { 3, 3, 3, 2 };
int fis_gRI80[] = { 3, 3, 3, 3 };
int* fis_gRI[] = { fis_gRI0, fis_gRI1, fis_gRI2, fis_gRI3, fis_gRI4, fis_gRI5, fis_gRI6, fis_gRI7, fis_gRI8,
fis_gRI9, fis_gRI10, fis_gRI11, fis_gRI12, fis_gRI13, fis_gRI14, fis_gRI15, fis_gRI16, fis_gRI17,
fis_gRI18, fis_gRI19, fis_gRI20, fis_gRI21, fis_gRI22, fis_gRI23, fis_gRI24, fis_gRI25, fis_gRI26,
fis_gRI27, fis_gRI28, fis_gRI29, fis_gRI30, fis_gRI31, fis_gRI32, fis_gRI33, fis_gRI34, fis_gRI35,
fis_gRI36, fis_gRI37, fis_gRI38, fis_gRI39, fis_gRI40, fis_gRI41, fis_gRI42, fis_gRI43, fis_gRI44,
fis_gRI45, fis_gRI46, fis_gRI47, fis_gRI48, fis_gRI49, fis_gRI50, fis_gRI51, fis_gRI52, fis_gRI53,
fis_gRI54, fis_gRI55, fis_gRI56, fis_gRI57, fis_gRI58, fis_gRI59, fis_gRI60, fis_gRI61, fis_gRI62,
fis_gRI63, fis_gRI64, fis_gRI65, fis_gRI66, fis_gRI67, fis_gRI68, fis_gRI69, fis_gRI70, fis_gRI71,
fis_gRI72, fis_gRI73, fis_gRI74, fis_gRI75, fis_gRI76, fis_gRI77, fis_gRI78, fis_gRI79, fis_gRI80 };

// Rule Outputs
int fis_gRO0[] = { 1 };
int fis_gRO1[] = { 2 };
int fis_gRO2[] = { 3 };
int fis_gRO3[] = { 4 };
int fis_gRO4[] = { 5 };
int fis_gRO5[] = { 6 };
int fis_gRO6[] = { 7 };
int fis_gRO7[] = { 8 };
int fis_gRO8[] = { 9 };
int fis_gRO9[] = { 10 };
int fis_gRO10[] = { 11 };
int fis_gRO11[] = { 12 };
int fis_gRO12[] = { 13 };
int fis_gRO13[] = { 14 };
int fis_gRO14[] = { 15 };
int fis_gRO15[] = { 16 };
int fis_gRO16[] = { 17 };
int fis_gRO17[] = { 18 };
int fis_gRO18[] = { 19 };
int fis_gRO19[] = { 20 };
int fis_gRO20[] = { 21 };
int fis_gRO21[] = { 22 };
int fis_gRO22[] = { 23 };
int fis_gRO23[] = { 24 };
int fis_gRO24[] = { 25 };
int fis_gRO25[] = { 26 };
int fis_gRO26[] = { 27 };
int fis_gRO27[] = { 28 };
int fis_gRO28[] = { 29 };
int fis_gRO29[] = { 30 };
int fis_gRO30[] = { 31 };
int fis_gRO31[] = { 32 };
int fis_gRO32[] = { 33 };
int fis_gRO33[] = { 34 };
int fis_gRO34[] = { 35 };
int fis_gRO35[] = { 36 };
int fis_gRO36[] = { 37 };
int fis_gRO37[] = { 38 };
```

```
int fis_gRO38[] = { 39 };
int fis_gRO39[] = { 40 };
int fis_gRO40[] = { 41 };
int fis_gRO41[] = { 42 };
int fis_gRO42[] = { 43 };
int fis_gRO43[] = { 44 };
int fis_gRO44[] = { 45 };
int fis_gRO45[] = { 46 };
int fis_gRO46[] = { 47 };
int fis_gRO47[] = { 48 };
int fis_gRO48[] = { 49 };
int fis_gRO49[] = { 50 };
int fis_gRO50[] = { 51 };
int fis_gRO51[] = { 52 };
int fis_gRO52[] = { 53 };
int fis_gRO53[] = { 54 };
int fis_gRO54[] = { 55 };
int fis_gRO55[] = { 56 };
int fis_gRO56[] = { 57 };
int fis_gRO57[] = { 58 };
int fis_gRO58[] = { 59 };
int fis_gRO59[] = { 60 };
int fis_gRO60[] = { 61 };
int fis_gRO61[] = { 62 };
int fis_gRO62[] = { 63 };
int fis_gRO63[] = { 64 };
int fis_gRO64[] = { 65 };
int fis_gRO65[] = { 66 };
int fis_gRO66[] = { 67 };
int fis_gRO67[] = { 68 };
int fis_gRO68[] = { 69 };
int fis_gRO69[] = { 70 };
int fis_gRO70[] = { 71 };
int fis_gRO71[] = { 72 };
int fis_gRO72[] = { 73 };
int fis_gRO73[] = { 74 };
int fis_gRO74[] = { 75 };
int fis_gRO75[] = { 76 };
int fis_gRO76[] = { 77 };
int fis_gRO77[] = { 78 };
int fis_gRO78[] = { 79 };
int fis_gRO79[] = { 80 };
int fis_gRO80[] = { 81 };
int* fis_gRO[] = { fis_gRO0, fis_gRO1, fis_gRO2, fis_gRO3, fis_gRO4, fis_gRO5, fis_gRO6, fis_gRO7,
fis_gRO8, fis_gRO9, fis_gRO10, fis_gRO11, fis_gRO12, fis_gRO13, fis_gRO14, fis_gRO15, fis_gRO16,
fis_gRO17, fis_gRO18, fis_gRO19, fis_gRO20, fis_gRO21, fis_gRO22, fis_gRO23, fis_gRO24,
fis_gRO25, fis_gRO26, fis_gRO27, fis_gRO28, fis_gRO29, fis_gRO30, fis_gRO31, fis_gRO32,
fis_gRO33, fis_gRO34, fis_gRO35, fis_gRO36, fis_gRO37, fis_gRO38, fis_gRO39, fis_gRO40,
fis_gRO41, fis_gRO42, fis_gRO43, fis_gRO44, fis_gRO45, fis_gRO46, fis_gRO47, fis_gRO48,
fis_gRO49, fis_gRO50, fis_gRO51, fis_gRO52, fis_gRO53, fis_gRO54, fis_gRO55, fis_gRO56,
fis_gRO57, fis_gRO58, fis_gRO59, fis_gRO60, fis_gRO61, fis_gRO62, fis_gRO63, fis_gRO64,
fis_gRO65, fis_gRO66, fis_gRO67, fis_gRO68, fis_gRO69, fis_gRO70, fis_gRO71, fis_gRO72,
fis_gRO73, fis_gRO74, fis_gRO75, fis_gRO76, fis_gRO77, fis_gRO78, fis_gRO79, fis_gRO80 };

// Input range Min
FIS_TYPE fis_gIMin[] = { 186.6827, 126.4076, 128.0265, 1291.5 };
```

```
// Input range Max
FIS_TYPE fis_gIMax[] = { 221.567, 127.9778, 128.9302, 48795 };

// Output range Min
FIS_TYPE fis_gOMin[] = { 30 };

// Output range Max
FIS_TYPE fis_gOMax[] = { 70 };

//***********************************************************************
// Data dependent support functions for Fuzzy Inference System
//***********************************************************************
// None for Sugeno

//***********************************************************************
// Fuzzy Inference System
//***********************************************************************
void fis_evaluate()
{
    FIS_TYPE fuzzyInput0[] = { 0, 0, 0 };
    FIS_TYPE fuzzyInput1[] = { 0, 0, 0 };
    FIS_TYPE fuzzyInput2[] = { 0, 0, 0 };
    FIS_TYPE fuzzyInput3[] = { 0, 0, 0 };
    FIS_TYPE* fuzzyInput[fis_gcI] = { fuzzyInput0, fuzzyInput1, fuzzyInput2, fuzzyInput3, };
    FIS_TYPE fuzzyOutput0[] = { 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,
0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,
0, 0, 0, 0, 0, 0, 0, 0, 0 };
    FIS_TYPE* fuzzyOutput[fis_gcO] = { fuzzyOutput0, };
    FIS_TYPE fuzzyRules[fis_gcR] = { 0 };
    FIS_TYPE fuzzyFires[fis_gcR] = { 0 };
    FIS_TYPE* fuzzyRuleSet[] = { fuzzyRules, fuzzyFires };
    FIS_TYPE sW = 0;

    // Transforming input to fuzzy Input
    int i, j, r, o;
    for (i = 0; i < fis_gcI; ++i)
    {
        for (j = 0; j < fis_gIMFCount[i]; ++j)
        {
            fuzzyInput[i][j] =
                (fis_gMF[fis_gMFI[i][j]])(g_fisInput[i], fis_gMFICoeff[i][j]);
        }
    }

    int index = 0;
    for (r = 0; r < fis_gcR; ++r)
    {
        if (fis_gRType[r] == 1)
        {
            fuzzyFires[r] = 1;
            for (i = 0; i < fis_gcI; ++i)
            {
                index = fis_gRI[r][i];
                if (index > 0)
                    fuzzyFires[r] = fis_prod(fuzzyFires[r], fuzzyInput[i][index - 1]);
```

```
        else if (index < 0)
          fuzzyFires[r] = fis_prod(fuzzyFires[r], 1 - fuzzyInput[i][-index - 1]);
        else
          fuzzyFires[r] = fis_prod(fuzzyFires[r], 1);
      }
    }
    else
    {
      fuzzyFires[r] = 0;
      for (i = 0; i < fis_gcI; ++i)
      {
        index = fis_gRI[r][i];
        if (index > 0)
          fuzzyFires[r] = fis_probor(fuzzyFires[r], fuzzyInput[i][index - 1]);
        else if (index < 0)
          fuzzyFires[r] = fis_probor(fuzzyFires[r], 1 - fuzzyInput[i][-index - 1]);
        else
          fuzzyFires[r] = fis_probor(fuzzyFires[r], 0);
      }
    }

    fuzzyFires[r] = fis_gRWeight[r] * fuzzyFires[r];
    sW += fuzzyFires[r];
  }

  if (sW == 0)
  {
    for (o = 0; o < fis_gcO; ++o)
    {
      g_fisOutput[o] = ((fis_gOMax[o] + fis_gOMin[o]) / 2);
    }
  }
  else
  {
    for (o = 0; o < fis_gcO; ++o)
    {
      FIS_TYPE sWI = 0.0;
      for (j = 0; j < fis_gOMFCount[o]; ++j)
      {
        fuzzyOutput[o][j] = fis_gMFOCoeff[o][j][fis_gcI];
        for (i = 0; i < fis_gcI; ++i)
        {
          fuzzyOutput[o][j] += g_fisInput[i] * fis_gMFOCoeff[o][j][i];
        }
      }

      for (r = 0; r < fis_gcR; ++r)
      {
        index = fis_gRO[r][o] - 1;
        sWI += fuzzyFires[r] * fuzzyOutput[o][index];
      }
      g_fisOutput[o] = sWI / sW;
    }
```

DATABASE CODE

```
def dbwrite():

    mydb = mysql.connector.connect(
    host = "localhost",
    user = "phpmyadmin",
    passwd = "thesisislove",
    database = "lettuce_db"
    )
```

IMAGE CAPTURE CODE

```
import cv2
import time
cap = cv2.VideoCapture(0)

def capture():

    cap.set(3, 1280)
    cap.set(4, 720)

    time.sleep(2)
    ret, frame = cap.read()
    time.sleep(1)

    return ret, frame

def release():
    cap.release()
```

IMAGE PROCESSING CODE

```
import cv2
import numpy as np
import matplotlib.pyplot as plt

def process(frame):

    raw_bgr1 = frame
    raw_bgr1 = raw_bgr1[135:656,305:825]

    raw_bgr = cv2.cvtColor(raw_bgr1, cv2.COLOR_BGR2RGB)
    raw_b, raw_g, raw_r = cv2.split(raw_bgr)

    x, y, z = raw_bgr.shape
    print("STAGE 1: COLOR FILTER")


    for i in range(x):
        for j in range(y):
            if raw_b[i,j]>90 and raw_g[i,j]>90 and raw_r[i,j]>90:

                raw_bgr[i,j,:] = raw_bgr[i,j,:]

            else:
                raw_bgr[i,j,:] = 0

    print("STAGE 2: COLOR CONVERSION")
    raw_lab = cv2.cvtColor(raw_bgr, cv2.COLOR_BGR2LAB)
    raw_gray = cv2.cvtColor(raw_bgr, cv2.COLOR_BGR2GRAY)
    raw_b, raw_g, raw_r = cv2.split(raw_bgr)
    raw_l, raw_av, raw_bv = cv2.split(raw_lab)

    print("STAGE 3: THRESHOLD")
    ret1, raw_thresh = cv2.threshold(raw_av,135,1,cv2.THRESH_BINARY_INV)

    print("STAGE 4: FILTERING")
    kernel = np.ones((3,3),np.uint8)
    raw_open = cv2.morphologyEx(raw_thresh, cv2.MORPH_OPEN, kernel)

    print("STAGE 5: MASKING")
    raw_bm = np.multiply(raw_open,raw_b)
    raw_gm = np.multiply(raw_open,raw_g)
    raw_rm = np.multiply(raw_open,raw_r)

    final = np.dstack((raw_rm, raw_gm, raw_bm))
```

```
    b, g, r = cv2.split(final)

    ycbcr = cv2.cvtColor(final, cv2.COLOR_RGB2YCR_CB)
    luma, Cblue, Cred = cv2.split(ycbcr)


    ret1, binary = cv2.threshold(final,1,255,cv2.THRESH_BINARY)

    print("STAGE 6: EXTRACTION")
    avg_y = luma[luma.nonzero()].mean()
    avg_cb = Cblue[Cblue.nonzero()].mean()
    avg_cr = Cred[Cred.nonzero()].mean()
    Pcount = np.count_nonzero(binary)

##    print(avg_y)
##    print(avg_cb)
##    print(avg_cr)
##    print(Pcount)

    return avg_y, avg_cb, avg_cr, Pcount
```

SERIAL COMMUNICATION CODE

```
import time
import serial

ser = serial.Serial("/dev/ttyACM2",9600)

def serialopen():
   ser.isOpen()

def serialclose():
   ser.close()

def sendcode(code):
   ser.write(bytes(code, "ascii"))
   time.sleep(2)

def receivecode():
   ser.readline()
   time.sleep(1)
```

MAIN SCRIPT

```
import cv2
import numpy as np
import matplotlib.pyplot as plt
import time
import serial
import mysql.connector
import f_imgcap as imgcam
import f_imgproc as imgproc
import f_database as db
import f_sercomms as sercomms

numplants = 2

print("INITIALIZE SERIAL COMMUNICATION")
ser = serial.Serial("/dev/ttyACM0",9600)

print("INITIALIZE DATABASE")

mydb = mysql.connector.connect(
    host = "localhost",
    user = "phpmyadmin",
    passwd = "thesisislove",
    database = "lettuce_db"
    )


sercomms.serialopen()
time.sleep(1)

##while True:
##
##    request = ser.readline()
##    time.sleep(1)
##    print(request)

##    if request == b'CAPTURE\r\n':

print('CAPTURE IMAGE')

sercomms.sendcode('CAPTURE')

ret, frame = imgcam.capture()
imgcam.release()

avg_y, avg_cb, avg_cr, Pcount = imgproc.process(frame)
```

```
y_str = str(round(avg_y,5))
Cb_str = str(round(avg_cb,5))
Cr_str = str(round(avg_cr,5))
Pcount_str = str(Pcount/numplants)

##print(y_str)
##print(Cb_str)
##print(Cr_str)
##print(Pcount_str)

print("STAGE 7: TRANSMISSION")

sercomms.sendcode('INPUT')
sercomms.sendcode(y_str)
sercomms.sendcode(Cb_str)
sercomms.sendcode(Cr_str)
sercomms.sendcode(Pcount_str)

print("END OF TRANSMISSION")

print("STAGE 8: WRITE TO DATABASE")

time.sleep(2)
sercomms.sendcode('OUTPUT')
time.sleep(5)



while ser.in_waiting:
    rqstatus = ser.readline()

    if rqstatus == b'READY\r\n':
        break

a = ser.readline()
print(a)
time.sleep(1)
b = ser.readline()
print(b)
time.sleep(1)
c = ser.readline()
print(c)
```

```
mycursor = mydb.cursor()
sql = "INSERT INTO light_db (TIME, STATUS, RGB, Y, CHROMA_B, CHROMA_R,
PIXEL_COUNT) VALUES (%s, %s, %s, %s, %s, %s, %s)"
val = (a,b,c,y_str,Cb_str,Cr_str,Pcount_str)
mycursor.execute(sql,val)
mydb.commit()
print("END OF PROGRAM")
```

APPENDIX D

SPECIFICATIONS AND DATASHEET

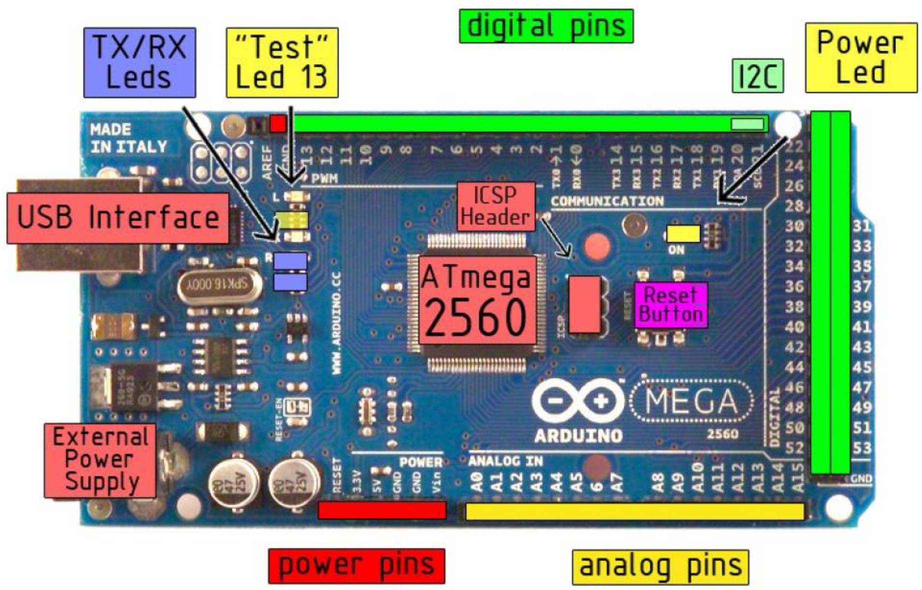
Technical Specification

EAGLE files: arduino-mega2560-reference-design.zip Schematic: arduino-mega2560-schematic.pdf

Summary

Microcontroller	ATmega2560
Operating Voltage	5V
Input Voltage (recommended)	7-12V
Input Voltage (limits)	6-20V
Digital I/O Pins	54 (of which 14 provide PWM output)
Analog Input Pins	16
DC Current per I/O Pin	40 mA
DC Current for 3.3V Pin	50 mA
Flash Memory	256 KB of which 8 KB used by bootloader
SRAM	8 KB
EEPROM	4 KB
Clock Speed	16 MHz

the board



Power

The Arduino Mega2560 can be powered via the USB connection or with an external power supply. The power source is selected automatically. External (non-USB) power can come either from an AC-to-DC adapter (wall-wart) or battery. The adapter can be connected by plugging a 2.1mm center-positive plug into the board's power jack. Leads from a battery can be inserted in the Gnd and Vin pin headers of the POWER connector.

The board can operate on an external supply of 6 to 20 volts. If supplied with less than 7V, however, the 5V pin may supply less than five volts and the board may be unstable. If using more than 12V, the voltage regulator may overheat and damage the board. The recommended range is 7 to 12 volts.

The Mega2560 differs from all preceding boards in that it does not use the FTDI USB-to-serial driver chip. Instead, it features the Atmega8U2 programmed as a USB-to-serial converter.

The power pins are as follows:

- **VIN.** The input voltage to the Arduino board when it's using an external power source (as opposed to 5 volts from the USB connection or other regulated power source). You can supply voltage through this pin, or, if supplying voltage via the power jack, access it through this pin.
- **5V.** The regulated power supply used to power the microcontroller and other components on the board. This can come either from VIN via an on-board regulator, or be supplied by USB or another regulated 5V supply.
- **3V3.** A 3.3 volt supply generated by the on-board regulator. Maximum current draw is 50 mA.
- **GND.** Ground pins.

Memory

The ATmega2560 has 256 KB of flash memory for storing code (of which 8 KB is used for the bootloader), 8 KB of SRAM and 4 KB of EEPROM (which can be read and written with the EEPROM library).

Input and Output

Each of the 54 digital pins on the Mega can be used as an input or output, using pinMode(), digitalWrite(), and digitalRead() functions. They operate at 5 volts. Each pin can provide or receive a maximum of 40 mA and has an internal pull-up resistor (disconnected by default) of 20-50 kOhms. In addition, some pins have specialized functions:

- **Serial: 0 (RX) and 1 (TX); Serial 1: 19 (RX) and 18 (TX); Serial 2: 17 (RX) and 16 (TX); Serial 3: 15 (RX) and 14 (TX).** Used to receive (RX) and transmit (TX) TTL serial data. Pins 0 and 1 are also connected to the corresponding pins of the ATmega8U2 USB-to-TTL Serial chip .
- **External Interrupts: 2 (interrupt 0), 3 (interrupt 1), 18 (interrupt 5), 19 (interrupt 4), 20 (interrupt 3), and 21 (interrupt 2).** These pins can be configured to trigger an interrupt on a low value, a rising or falling edge, or a change in value. See the attachInterrupt() function for details.
- **PWM: 0 to 13.** Provide 8-bit PWM output with the analogWrite() function.
- **SPI: 50 (MISO), 51 (MOSI), 52 (SCK), 53 (SS).** These pins support SPI communication, which, although provided by the underlying hardware, is not currently included in the Arduino language. The SPI pins are also broken out on the ICSP header, which is physically compatible with the Duemilanove and Diecimila.
- **LED: 13.** There is a built-in LED connected to digital pin 13. When the pin is HIGH value, the LED is on, when the pin is LOW, it's off.
- **I^2C: 20 (SDA) and 21 (SCL).** Support I^2C (TWI) communication using the Wire library (documentation on the Wiring website). Note that these pins are not in the same location as the I^2C pins on the Duemilanove.

The Mega2560 has 16 analog inputs, each of which provide 10 bits of resolution (i.e. 1024 different values). By default they measure from ground to 5 volts, though is it possible to change the upper end of their range using the AREF pin and analogReference() function.

There are a couple of other pins on the board:

- **AREF.** Reference voltage for the analog inputs. Used with analogReference().
- **Reset.** Bring this line LOW to reset the microcontroller. Typically used to add a reset button to shields which block the one on the board.

Communication

The Arduino Mega2560 has a number of facilities for communicating with a computer, another Arduino, or other microcontrollers. The ATmega2560 provides four hardware UARTs for TTL (5V) serial communication. An ATmega8U2 on the board channels one of these over USB and provides a virtual com port to software on the computer (Windows machines will need a .inf file, but OSX and Linux machines will recognize the board as a COM port automatically. The Arduino software includes a serial monitor which allows simple textual data to be sent to and from the board. The RX and TX LEDs on the board will flash when data is being transmitted via the ATmega8U2 chip and USB connection to the computer (but not for serial communication on pins 0 and 1).

A SoftwareSerial library allows for serial communication on any of the Mega's digital pins.

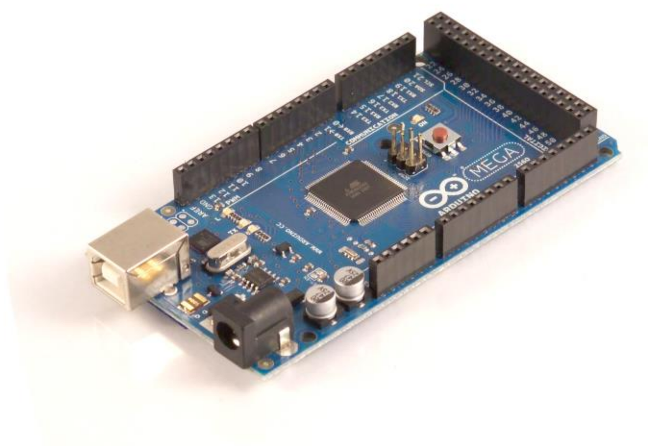
The ATmega2560 also supports I2C (TWI) and SPI communication. The Arduino software includes a Wire library to simplify use of the I2C bus; see the documentation on the Wiring website for details. To use the SPI communication, please see the ATmega2560 datasheet.

Programming

The Arduino Mega2560 can be programmed with the Arduino software (download). For details, see the reference and tutorials.

The Atmega2560 on the Arduino Mega comes preburned with a bootloader that allows you to upload new code to it without the use of an external hardware programmer. It communicates using the original STK500 protocol (reference, C header files).

You can also bypass the bootloader and program the microcontroller through the ICSP (In-Circuit Serial Programming) header; see these instructions for details.



Automatic (Software) Reset

Rather then requiring a physical press of the reset button before an upload, the Arduino Mega2560 is designed in a way that allows it to be reset by software running on a connected computer. One of the hardware flow control lines (DTR) of the ATmega8U2 is connected to the reset line of the ATmega2560 via a 100 nanofarad capacitor. When this line is asserted (taken low), the reset line drops long enough to reset the chip. The Arduino software uses this capability to allow you to upload code by simply pressing the upload button in the Arduino environment. This means that the bootloader can have a shorter timeout, as the lowering of DTR can be well-coordinated with the start of the upload.

This setup has other implications. When the Mega2560 is connected to either a computer running Mac OS X or Linux, it resets each time a connection is made to it from software (via USB). For the following half-second or so, the bootloader is running on the Mega2560. While it is programmed to ignore malformed data (i.e. anything besides an upload of new code), it will intercept the first few bytes of data sent to the board after a connection is opened. If a sketch running on the board receives one-time configuration or other data when it first starts, make sure that the software with which it communicates waits a second after opening the connection and before sending this data.

The Mega contains a trace that can be cut to disable the auto-reset. The pads on either side of the trace can be soldered together to re-enable it. It's labeled "RESET-EN". You may also be able to disable the auto-reset by connecting a 110 ohm resistor from 5V to the reset line; see this forum thread for details.

USB Overcurrent Protection

The Arduino Mega has a resettable polyfuse that protects your computer's USB ports from shorts and overcurrent. Although most computers provide their own internal protection, the fuse provides an extra layer of protection. If more than 500 mA is applied to the USB port, the fuse will automatically break the connection until the short or overload is removed.

Physical Characteristics and Shield Compatibility

The maximum length and width of the Mega PCB are 4 and 2.1 inches respectively, with the USB connector and power jack extending beyond the former dimension. Three screw holes allow the board to be attached to a surface or case. Note that the distance between digital pins 7 and 8 is 160 mil (0.16"), not an even multiple of the 100 mil spacing of the other pins.

The Mega is designed to be compatible with most shields designed for the Diecimila or Duemilanove. Digital pins 0 to 13 (and the adjacent AREF and GND pins), analog inputs 0 to 5, the power header, and ICSP header are all in equivalent locations. Further the main UART (serial port) is located on the same pins (0 and 1), as are external interrupts 0 and 1 (pins 2 and 3 respectively). SPI is available through the ICSP header on both the Mega and Duemilanove / Diecimila. **Please note that I^2C is not located on the same pins on the Mega (20 and 21) as the Duemilanove / Diecimila (analog inputs 4 and 5).**

How to use Arduino

Arduino can sense the environment by receiving input from a variety of sensors and can affect its surroundings by controlling lights, motors, and other actuators. The microcontroller on the board is programmed using the Arduino programming language (based on Wiring) and the Arduino development environment (based on Processing). Arduino projects can be stand-alone or they can communicate with software on running on a computer (e.g. Flash, Processing, MaxMSP).

Arduino is a cross-platoform program. You'll have to follow different instructions for your personal OS. Check on the Arduino site for the latest instructions. *http://arduino.cc/en/Guide/HomePage*

Linux Install **Windows Install** **Mac Install**

Once you have downloaded/unzipped the arduino IDE, you can Plug the Arduino to your PC via USB cable.

Blink led

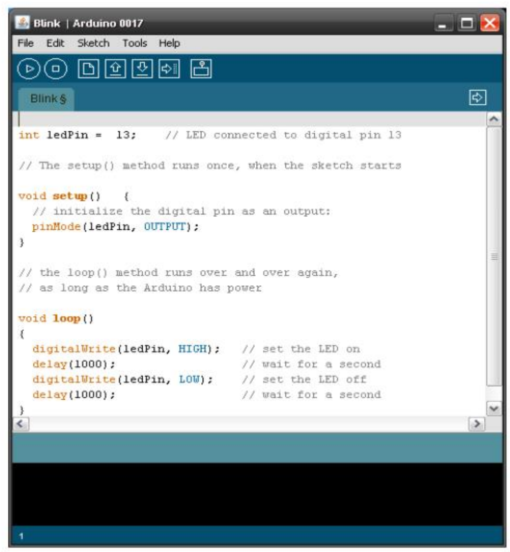
Now you're actually ready to "burn" your first program on the arduino board. To select "blink led", the physical translation of the well known programming "hello world", select

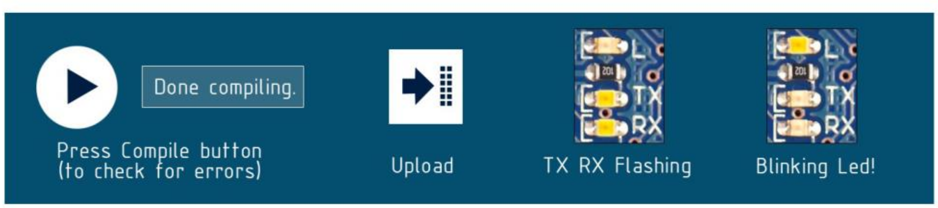
**File>Sketchbook>
Arduino-0017>Examples>
Digital>Blink**

Once you have your skecth you'll see something very close to the screenshot on the right.

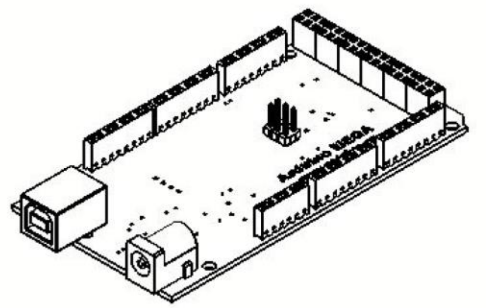
In **Tools>Board** select MEGA

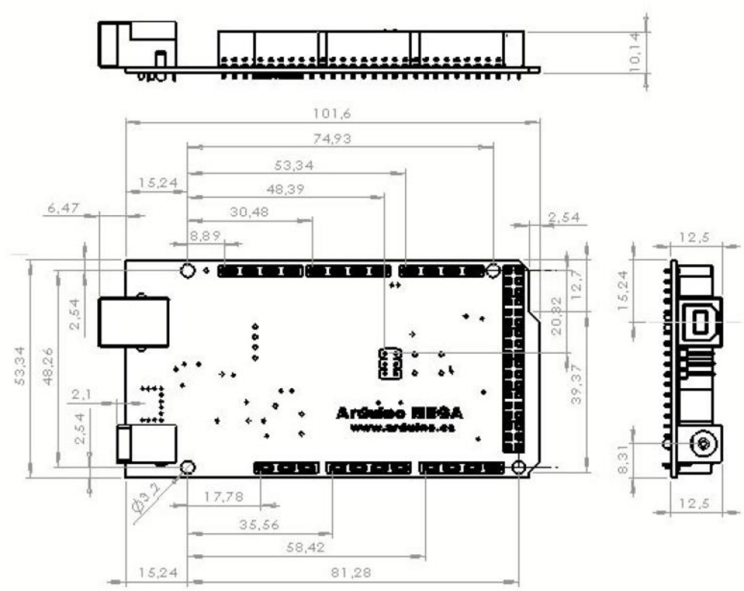
Now you have to go to
Tools>SerialPort
and select the right serial port, the one arduino is attached to.





Dimensioned Drawing





logitech

C922 PRO

Stream webcam

DESIGNED FOR SERIOUS STREAMERS.

Designed for serious streamers, the Logitech® C922 Pro Stream Webcam lets you stream and record vibrant, true-to-life HD 1080p video that captures the most exciting details at 30fps. H.264–an advanced compression technology that demands less network bandwidth–makes sure your uploads are fast and smooth. Use the customisable background replacement to integrate live images while broadcasting on Twitch and YouTube. The video automatically adjusts to low light and two omnidirectional mics capture stereo audio from every angle. The tabletop tripod comes with a swivel mount and extends to 18.5 cm so that you can adjust C922 to the most flattering angle.

WHAT'S IN THE BOX

- Pro webcam for streaming
- Tripod
- User documentation
- 2-year manufacturer's guarantee and full product support

FEATURES

- Full HD 1080p at 30fps/720p at 60fps streaming
- Customisable background replacement
- Automatic low-light correction
- Two omnidirectional mics
- Fully adjustable tabletop tripod

logitech

PACKAGE SPECIFICATIONS

	Primary pack		Master shipper carton	
Part #	960-001088		n/a	
Bar code	5099206066977	(EAN-13)	50992060669714	(SCC-14)
Weight	320	gr	2854	gr
Length	13.6	cm	28.2	cm
Width	8	cm	17	cm
Height/depth	13.6	cm	28.8	cm
Volume	1.480	dm^3	0.0138	m^3
1 primary pack	1		n/a	
1 intermediate pack	0		n/a	
1 master shipper carton	8		1	
1 pallet EURO	1064		133	
1 container 20 ft	11704		1463	
1 container 40 ft	24472		3059	
1 container 40 ft HQ	24472		3059	

SYSTEM REQUIREMENTS

- Compatible with: Windows® 7, Windows® 8, Windows® 10 or later; Mac OS X 10.9 or later; Chrome OS and Android v 5.0 or above
- USB port
- Internet access. Visit your preferred video streaming solution provider's website for exact information on system and performance requirements
- Works with XSplit, OBS

ADDRESS	BIT 7 MSB	BIT 6	BIT 5	BIT 4	BIT 3	BIT 2	BIT 1	BIT 0 LSB	FUNCTION	RANGE
00h	0	10 Seconds			Seconds				Seconds	00–59
01h	0	10 Minutes			Minutes				Minutes	00–59
02h	0	12/$\overline{24}$	$\overline{AM}$/PM 20 Hour	10 Hour	Hour				Hours	1–12 + $\overline{AM}$/PM 00–23
03h	0	0	0	0	0	Day			Day	1–7
04h	0	0	10 Date		Date				Date	01–31
05h	Century	0	0	10 Month	Month				Month/ Century	01–12 + Century
06h	10 Year				Year				Year	00–99
07h	A1M1	10 Seconds			Seconds				Alarm 1 Seconds	00–59
08h	A1M2	10 Minutes			Minutes				Alarm 1 Minutes	00–59
09h	A1M3	12/$\overline{24}$	$\overline{AM}$/PM 20 Hour	10 Hour	Hour				Alarm 1 Hours	1–12 + $\overline{AM}$/PM 00–23
0Ah	A1M4	DY/DT	10 Date		Day				Alarm 1 Day	1–7
					Date				Alarm 1 Date	1–31
0Bh	A2M2	10 Minutes			Minutes				Alarm 2 Minutes	00–59
0Ch	A2M3	12/$\overline{24}$	$\overline{AM}$/PM 20 Hour	10 Hour	Hour				Alarm 2 Hours	1–12 + $\overline{AM}$/PM 00–23
0Dh	A2M4	DY/$\overline{DT}$	10 Date		Day				Alarm 2 Day	1–7
					Date				Alarm 2 Date	1–31
0Eh	$\overline{EOSC}$	BBSQW	CONV	RS2	RS1	INTCN	A2IE	A1IE	Control	—
0Fh	OSF	0	0	0	EN32kHz	BSY	A2F	A1F	Control/Status	—
10h	SIGN	DATA	DATA	DATA	DATA	DATA	DATA	DATA	Aging Offset	—
11h	SIGN	DATA	DATA	DATA	DATA	DATA	DATA	DATA	MSB of Temp	—
12h	DATA	DATA	0	0	0	0	0	0	LSB of Temp	—

Figure 1. Timekeeping Registers

Note: *Unless otherwise specified, the registers' state is not defined when power is first applied.*

Address Map

Figure 1 shows the address map for the DS3231 timekeeping registers. During a multibyte access, when the address pointer reaches the end of the register space (12h), it wraps around to location 00h. On an I²C START or address pointer incrementing to location 00h, the current time is transferred to a second set of registers. The time information is read from these secondary registers, while the clock may continue to run. This eliminates the need to reread the registers in case the main registers update during a read.

I²C Interface

The I²C interface is accessible whenever either V_{CC} or V_{BAT} is at a valid level. If a microcontroller connected to the DS3231 resets because of a loss of V_{CC} or other event, it is possible that the microcontroller and DS3231 I²C communications could become unsynchronized, e.g., the microcontroller resets while reading data from the DS3231. When the microcontroller resets, the DS3231 I²C interface may be placed into a known state by toggling SCL until SDA is observed to be at a high level. At that point the microcontroller should pull SDA low while SCL is high, generating a START condition.

Clock and Calendar

The time and calendar information is obtained by reading the appropriate register bytes. Figure 1 illustrates the RTC registers. The time and calendar data are set or initialized by writing the appropriate register bytes. The contents of the time and calendar registers are in the binary-coded decimal (BCD) format. The DS3231 can be run in either 12-hour or 24-hour mode. Bit 6 of the hours register is defined as the 12- or 24-hour mode select bit. When high, the 12-hour mode is selected. In the 12-hour mode, bit 5 is the $\overline{AM}$/PM bit with logic-high being PM. In the 24-hour mode, bit 5 is the 20-hour bit (20–23 hours). The century bit (bit 7 of the month register) is toggled when the years register overflows from 99 to 00.

The day-of-week register increments at midnight. Values that correspond to the day of week are user-defined but must be sequential (i.e., if 1 equals Sunday, then 2 equals Monday, and so on). Illogical time and date entries result in undefined operation.

When reading or writing the time and date registers, secondary (user) buffers are used to prevent errors when the internal registers update. When reading the time and date registers, the user buffers are synchronized to the internal registers on any START and when the register pointer rolls over to zero. The time information is read from these secondary registers, while the clock continues to run. This eliminates the need to reread the registers in case the main registers update during a read.

The countdown chain is reset whenever the seconds register is written. Write transfers occur on the acknowledge from the DS3231. Once the countdown chain is reset, to avoid rollover issues the remaining time and date registers must be written within 1 second. The 1Hz square-wave output, if enabled, transitions high 500ms after the seconds data transfer, provided the oscillator is already running.

Alarms

The DS3231 contains two time-of-day/date alarms. Alarm 1 can be set by writing to registers 07h to 0Ah. Alarm 2 can be set by writing to registers 0Bh to 0Dh. The alarms can be programmed (by the alarm enable and INTCN bits of the control register) to activate the $\overline{INT}$/SQW output on an alarm match condition. Bit 7 of each of the time-of-day/date alarm registers are mask bits (Table 2). When all the mask bits for each alarm are logic 0, an alarm only occurs when the values in the timekeeping registers match the corresponding values stored in the time-of-day/date alarm registers. The alarms can also be programmed to repeat every second, minute, hour, day, or date. Table 2 shows the possible settings. Configurations not listed in the table will result in illogical operation.

The DY/$\overline{DT}$ bits (bit 6 of the alarm day/date registers) control whether the alarm value stored in bits 0 to 5 of that register reflects the day of the week or the date of the month. If DY/$\overline{DT}$ is written to logic 0, the alarm will be the result of a match with date of the month. If DY/$\overline{DT}$ is written to logic 1, the alarm will be the result of a match with day of the week.

When the RTC register values match alarm register settings, the corresponding Alarm Flag 'A1F' or 'A2F' bit is set to logic 1. If the corresponding Alarm Interrupt Enable 'A1IE' or 'A2IE' is also set to logic 1 and the INTCN bit is set to logic 1, the alarm condition will activate the $\overline{INT}$/SQW signal. The match is tested on the once-per-second update of the time and date registers.

Table 2. Alarm Mask Bits

DY/$\overline{DT}$	ALARM 1 REGISTER MASK BITS (BIT 7)				ALARM RATE
	A1M4	A1M3	A1M2	A1M1	
X	1	1	1	1	Alarm once per second
X	1	1	1	0	Alarm when seconds match
X	1	1	0	0	Alarm when minutes and seconds match
X	1	0	0	0	Alarm when hours, minutes, and seconds match
0	0	0	0	0	Alarm when date, hours, minutes, and seconds match
1	0	0	0	0	Alarm when day, hours, minutes, and seconds match

DY/$\overline{DT}$	ALARM 2 REGISTER MASK BITS (BIT 7)			ALARM RATE
	A2M4	A2M3	A2M2	
X	1	1	1	Alarm once per minute (00 seconds of every minute)
X	1	1	0	Alarm when minutes match
X	1	0	0	Alarm when hours and minutes match
0	0	0	0	Alarm when date, hours, and minutes match
1	0	0	0	Alarm when day, hours, and minutes match

Control Register (0Eh)

	BIT 7	BIT 6	BIT 5	BIT 4	BIT 3	BIT 2	BIT 1	BIT 0
NAME:	$\overline{\text{EOSC}}$	BBSQW	CONV	RS2	RS1	INTCN	A2IE	A1IE
POR:	0	0	0	1	1	1	0	0

Special-Purpose Registers

The DS3231 has two additional registers (control and status) that control the real-time clock, alarms, and square-wave output.

Control Register (0Eh)

Bit 7: Enable Oscillator ($\overline{\text{EOSC}}$). When set to logic 0, the oscillator is started. When set to logic 1, the oscillator is stopped when the DS3231 switches to V_{BAT}. This bit is clear (logic 0) when power is first applied. When the DS3231 is powered by V_{CC}, the oscillator is always on regardless of the status of the $\overline{\text{EOSC}}$ bit. When $\overline{\text{EOSC}}$ is disabled, all register data is static.

Bit 6: Battery-Backed Square-Wave Enable (BBSQW). When set to logic 1 with INTCN = 0 and $V_{CC} < V_{PF}$, this bit enables the square wave. When BBSQW is logic 0, the $\overline{\text{INT}}$/SQW pin goes high impedance when $V_{CC} < V_{PF}$. This bit is disabled (logic 0) when power is first applied.

Bit 5: Convert Temperature (CONV). Setting this bit to 1 forces the temperature sensor to convert the temperature into digital code and execute the TCXO algorithm to update the capacitance array to the oscillator. This can only happen when a conversion is not already in progress. The user should check the status bit BSY before forcing the controller to start a new TCXO execution. A user-initiated temperature conversion does not affect the internal 64-second update cycle.

A user-initiated temperature conversion does not affect the BSY bit for approximately 2ms. The CONV bit remains at a 1 from the time it is written until the conversion is finished, at which time both CONV and BSY go to 0. The CONV bit should be used when monitoring the status of a user-initiated conversion.

Bits 4 and 3: Rate Select (RS2 and RS1). These bits control the frequency of the square-wave output when the square wave has been enabled. The following table shows the square-wave frequencies that can be selected with the RS bits. These bits are both set to logic 1 (8.192kHz) when power is first applied.

SQUARE-WAVE OUTPUT FREQUENCY

RS2	RS1	SQUARE-WAVE OUTPUT FREQUENCY
0	0	1Hz
0	1	1.024kHz
1	0	4.096kHz
1	1	8.192kHz

Bit 2: Interrupt Control (INTCN). This bit controls the $\overline{\text{INT}}$/SQW signal. When the INTCN bit is set to logic 0, a square wave is output on the $\overline{\text{INT}}$/SQW pin. When the INTCN bit is set to logic 1, then a match between the timekeeping registers and either of the alarm registers activates the $\overline{\text{INT}}$/SQW output (if the alarm is also enabled). The corresponding alarm flag is always set regardless of the state of the INTCN bit. The INTCN bit is set to logic 1 when power is first applied.

Bit 1: Alarm 2 Interrupt Enable (A2IE). When set to logic 1, this bit permits the alarm 2 flag (A2F) bit in the status register to assert $\overline{\text{INT}}$/SQW (when INTCN = 1). When the A2IE bit is set to logic 0 or INTCN is set to logic 0, the A2F bit does not initiate an interrupt signal. The A2IE bit is disabled (logic 0) when power is first applied.

Bit 0: Alarm 1 Interrupt Enable (A1IE). When set to logic 1, this bit permits the alarm 1 flag (A1F) bit in the status register to assert $\overline{\text{INT}}$/SQW (when INTCN = 1). When the A1IE bit is set to logic 0 or INTCN is set to logic 0, the A1F bit does not initiate the $\overline{\text{INT}}$/SQW signal. The A1IE bit is disabled (logic 0) when power is first applied.

Status Register (0Fh)

	BIT 7	BIT 6	BIT 5	BIT 4	BIT 3	BIT 2	BIT 1	BIT 0
NAME:	OSF	0	0	0	EN32kHz	BSY	A2F	A1F
POR:	1	0	0	0	1	X	X	X

Status Register (0Fh)

Bit 7: Oscillator Stop Flag (OSF). A logic 1 in this bit indicates that the oscillator either is stopped or was stopped for some period and may be used to judge the validity of the timekeeping data. This bit is set to logic 1 any time that the oscillator stops. The following are examples of conditions that can cause the OSF bit to be set:

1) The first time power is applied.
2) The voltages present on both V_{CC} and V_{BAT} are insufficient to support oscillation.
3) The $\overline{\text{EOSC}}$ bit is turned off in battery-backed mode.
4) External influences on the crystal (i.e., noise, leakage, etc.).

This bit remains at logic 1 until written to logic 0.

Bit 3: Enable 32kHz Output (EN32kHz). This bit controls the status of the 32kHz pin. When set to logic 1, the 32kHz pin is enabled and outputs a 32.768kHz square-wave signal. When set to logic 0, the 32kHz pin goes to a high-impedance state. The initial power-up state of this bit is logic 1, and a 32.768kHz square-wave signal appears at the 32kHz pin after a power source is applied to the DS3231 (if the oscillator is running).

Bit 2: Busy (BSY). This bit indicates the device is busy executing TCXO functions. It goes to logic 1 when the conversion signal to the temperature sensor is asserted and then is cleared when the device is in the 1-minute idle state.

Bit 1: Alarm 2 Flag (A2F). A logic 1 in the alarm 2 flag bit indicates that the time matched the alarm 2 registers. If the A2IE bit is logic 1 and the INTCN bit is set to logic 1, the $\overline{\text{INT}}$/SQW pin is also asserted. A2F is cleared when written to logic 0. This bit can only be written to logic 0. Attempting to write to logic 1 leaves the value unchanged.

Bit 0: Alarm 1 Flag (A1F). A logic 1 in the alarm 1 flag bit indicates that the time matched the alarm 1 registers. If the A1IE bit is logic 1 and the INTCN bit is set to logic 1, the $\overline{\text{INT}}$/SQW pin is also asserted. A1F is cleared when written to logic 0. This bit can only be written to logic 0. Attempting to write to logic 1 leaves the value unchanged.

Aging Offset

The aging offset register takes a user-provided value to add to or subtract from the codes in the capacitance array registers. The code is encoded in two's complement, with bit 7 representing the sign bit. One LSB represents one small capacitor to be switched in or out of the capacitance array at the crystal pins. The aging offset register capacitance value is added or subtracted from the capacitance value that the device calculates for each temperature compensation. The offset register is added to the capacitance array during a normal temperature conversion, if the temperature changes from the previous conversion, or during a manual user conversion (setting the CONV bit). To see the effects of the aging register on the 32kHz output frequency immediately, a manual conversion should be started after each aging register change.

Positive aging values add capacitance to the array, slowing the oscillator frequency. Negative values remove capacitance from the array, increasing the oscillator frequency.

The change in ppm per LSB is different at different temperatures. The frequency vs. temperature curve is shifted by the values used in this register. At +25°C, one LSB typically provides about 0.1ppm change in frequency.

Use of the aging register is not needed to achieve the accuracy as defined in the EC tables, but could be used to help compensate for aging at a given temperature. See the *Typical Operating Characteristics* section for a graph showing the effect of the register on accuracy over temperature.

Aging Offset (10h)

	BIT 7	BIT 6	BIT 5	BIT 4	BIT 3	BIT 2	BIT 1	BIT 0
NAME:	Sign	Data	Data	Data	Data	Data	Data	Data
POR:	0	0	0	0	0	0	0	0

Temperature Register (Upper Byte) (11h)

	BIT 7	BIT 6	BIT 5	BIT 4	BIT 3	BIT 2	BIT 1	BIT 0
NAME:	Sign	Data	Data	Data	Data	Data	Data	Data
POR:	0	0	0	0	0	0	0	0

Temperature Register (Lower Byte) (12h)

	BIT 7	BIT 6	BIT 5	BIT 4	BIT 3	BIT 2	BIT 1	BIT 0
NAME:	Data	Data	0	0	0	0	0	0
POR:	0	0	0	0	0	0	0	0

Temperature Registers (11h–12h)

Temperature is represented as a 10-bit code with a resolution of 0.25°C and is accessible at location 11h and 12h. The temperature is encoded in two's complement format. The upper 8 bits, the integer portion, are at location 11h and the lower 2 bits, the fractional portion, are in the upper nibble at location 12h. For example, 00011001 01b = +25.25°C. Upon power reset, the registers are set to a default temperature of 0°C and the controller starts a temperature conversion. The temperature is read on initial application of V_{CC} or I^2C access on V_{BAT} and once every 64 seconds afterwards. The temperature registers are updated after each user-initiated conversion and on every 64-second conversion. The temperature registers are read-only.

I^2C Serial Data Bus

The DS3231 supports a bidirectional I^2C bus and data transmission protocol. A device that sends data onto the bus is defined as a transmitter and a device receiving data is defined as a receiver. The device that controls the message is called a master. The devices that are controlled by the master are slaves. The bus must be controlled by a master device that generates the serial clock (SCL), controls the bus access, and generates the START and STOP conditions. The DS3231 operates as a slave on the I^2C bus. Connections to the bus are made through the SCL input and open-drain SDA I/O lines. Within the bus specifications, a standard mode (100kHz maximum clock rate) and a fast mode (400kHz maximum clock rate) are defined. The DS3231 works in both modes.

The following bus protocol has been defined (Figure 2):

- Data transfer may be initiated only when the bus is not busy.
- During data transfer, the data line must remain stable whenever the clock line is high. Changes in the data line while the clock line is high are interpreted as control signals.

Accordingly, the following bus conditions have been defined:

Bus not busy: Both data and clock lines remain high.

START data transfer: A change in the state of the data line from high to low, while the clock line is high, defines a START condition.

STOP data transfer: A change in the state of the data line from low to high, while the clock line is high, defines a STOP condition.

Data valid: The state of the data line represents valid data when, after a START condition, the data line is stable for the duration of the high period of the clock signal. The data on the line must be changed during the low period of the clock signal. There is one clock pulse per bit of data.

Each data transfer is initiated with a START condition and terminated with a STOP condition. The number of data bytes transferred between the START and the STOP conditions is not limited, and is determined by the master device. The information is transferred byte-wise and each receiver acknowledges with a ninth bit.

Acknowledge: Each receiving device, when addressed, is obliged to generate an acknowledge after the reception of each byte. The master device must generate an extra clock pulse, which is associated with this acknowledge bit.

A device that acknowledges must pull down the SDA line during the acknowledge clock pulse in such a way that the SDA line is stable low during the high period of the acknowledge-related clock pulse. Of course, setup and hold times must be taken into account. A master must signal an end of data to the slave by not generat-

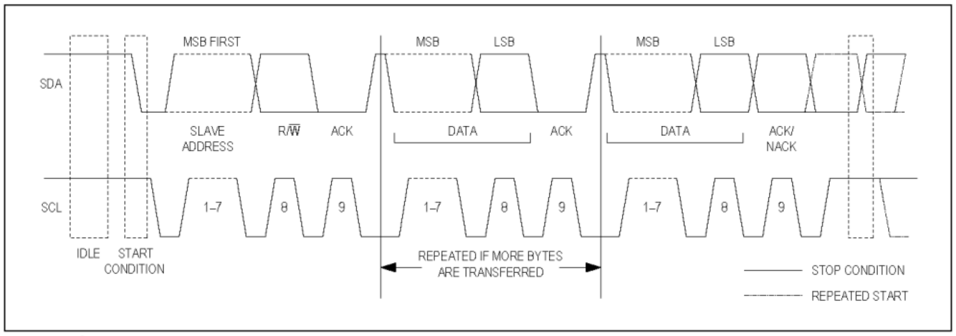


Figure 2. I2C Data Transfer Overview

ing an acknowledge bit on the last byte that has been clocked out of the slave. In this case, the slave must leave the data line high to enable the master to generate the STOP condition.

Figures 3 and 4 detail how data transfer is accomplished on the I2C bus. Depending upon the state of the R/$\overline{W}$ bit, two types of data transfer are possible:

Data transfer from a master transmitter to a slave receiver. The first byte transmitted by the master is the slave address. Next follows a number of data bytes. The slave returns an acknowledge bit after each received byte. Data is transferred with the most significant bit (MSB) first.

Data transfer from a slave transmitter to a master receiver. The first byte (the slave address) is transmitted by the master. The slave then returns an acknowledge bit. Next follows a number of data bytes transmitted by the slave to the master. The master returns an acknowledge bit after all received bytes other than the

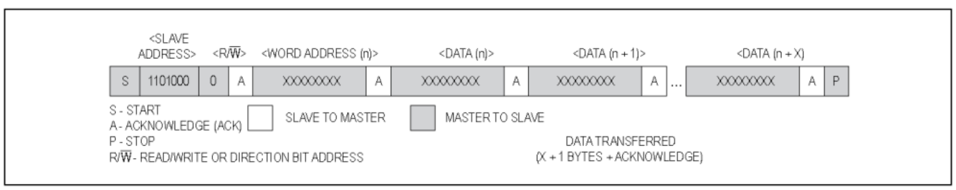


Figure 3. Data Write—Slave Receiver Mode

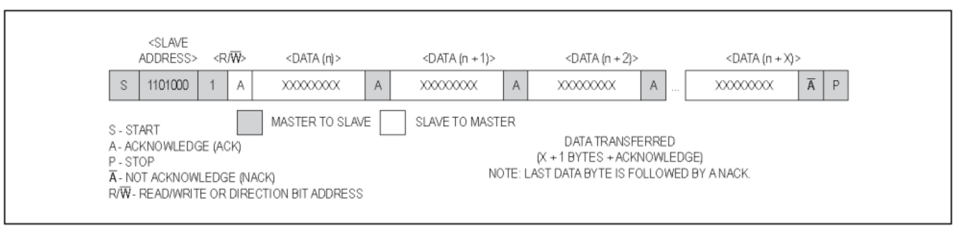


Figure 4. Data Read—Slave Transmitter Mode

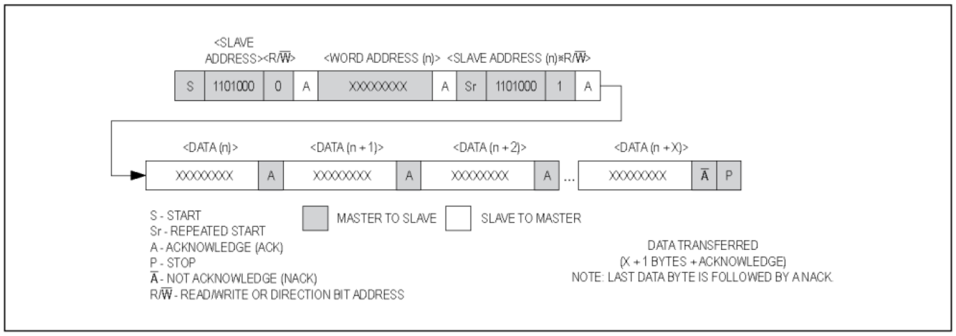


Figure 5. Data Write/Read (Write Pointer, Then Read)—Slave Receive and Transmit

last byte. At the end of the last received byte, a not acknowledge is returned.

The master device generates all the serial clock pulses and the START and STOP conditions. A transfer is ended with a STOP condition or with a repeated START condition. Since a repeated START condition is also the beginning of the next serial transfer, the bus will not be released. Data is transferred with the most significant bit (MSB) first.

The DS3231 can operate in the following two modes:

Slave receiver mode (DS3231 write mode): Serial data and clock are received through SDA and SCL. After each byte is received, an acknowledge bit is transmitted. START and STOP conditions are recognized as the beginning and end of a serial transfer. Address recognition is performed by hardware after reception of the slave address and direction bit. The slave address byte is the first byte received after the master generates the START condition. The slave address byte contains the 7-bit DS3231 address, which is 1101000, followed by the direction bit (R/$\overline{W}$), which is 0 for a write. After receiving and decoding the slave address byte, the DS3231 outputs an acknowledge on SDA. After the DS3231 acknowledges the slave address + write bit, the master transmits a word address to the DS3231. This sets the register pointer on the DS3231, with the DS3231 acknowledging the transfer. The master may then transmit zero or more bytes of data, with the DS3231 acknowledging each byte received. The register pointer increments after each data byte is transferred. The master generates a STOP condition to terminate the data write.

Slave transmitter mode (DS3231 read mode): The first byte is received and handled as in the slave receiver mode. However, in this mode, the direction bit indicates that the transfer direction is reversed. Serial data is transmitted on SDA by the DS3231 while the serial clock is input on SCL. START and STOP conditions are recognized as the beginning and end of a serial transfer. Address recognition is performed by hardware after reception of the slave address and direction bit. The slave address byte is the first byte received after the master generates a START condition. The slave address byte contains the 7-bit DS3231 address, which is 1101000, followed by the direction bit (R/$\overline{W}$), which is 1 for a read. After receiving and decoding the slave address byte, the DS3231 outputs an acknowledge on SDA. The DS3231 then begins to transmit data starting with the register address pointed to by the register pointer. If the register pointer is not written to before the initiation of a read mode, the first address that is read is the last one stored in the register pointer. The DS3231 must receive a not acknowledge to end a read.

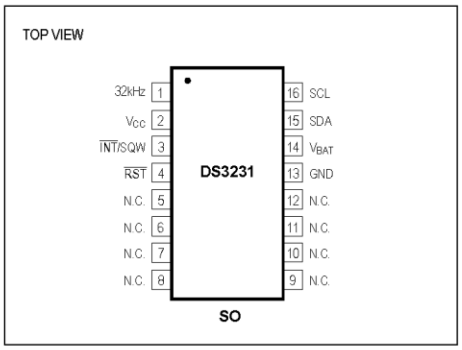
Handling, PCB Layout, and Assembly

The DS3231 package contains a quartz tuning-fork crystal. Pick-and-place equipment can be used, but precautions should be taken to ensure that excessive shocks are avoided. Ultrasonic cleaning should be avoided to prevent damage to the crystal.

Avoid running signal traces under the package, unless a ground plane is placed between the package and the signal line. All N.C. (no connect) pins must be connected to ground.

Moisture-sensitive packages are shipped from the factory dry packed. Handling instructions listed on the package label must be followed to prevent damage during reflow. Refer to the IPC/JEDEC J-STD-020 standard for moisture-sensitive device (MSD) classifications and reflow profiles. Exposure to reflow is limited to 2 times maximum.

Pin Configuration



Chip Information

SUBSTRATE CONNECTED TO GROUND

PROCESS: CMOS

Ordering Information

PART	TEMP RANGE	PIN-PACKAGE
DS3231S#	0°C to +70°C	16 SO
DS3231SN#	-40°C to +85°C	16 SO

#Denotes an RoHS-compliant device that may include lead (Pb) that is exempt under RoHS requirements. The lead finish is JESD97 category e3, and is compatible with both lead-based and lead-free soldering processes. A "#" anywhere on the top mark denotes an RoHS-compliant device.

Package Information

For the latest package outline information and land patterns (footprints), go to www.maximintegrated.com/packages. Note that a "+", "#", or "-" in the package code indicates RoHS status only. Package drawings may show a different suffix character, but the drawing pertains to the package regardless of RoHS status.

PACKAGE TYPE	PACKAGE CODE	OUTLINE NO.	LAND PATTERN NO.
16 SO	W16#H2	21-0042	90-0107

Revision History

REVISION NUMBER	REVISION DATE	DESCRIPTION	PAGES CHANGED
0	1/05	Initial release.	—
1	2/05	Changed Digital Temp Sensor Output from ±2°C to ±3°C.	1, 3
		Updated *Typical Operating Circuit*.	1
		Changed T_A = -40°C to +85°C to T_A = T_{MIN} to T_{MAX}.	2, 3, 4
		Updated *Block Diagram*.	8
2	6/05	Added "UL Recognized" to Features; added lead-free packages and removed S from top mark info in *Ordering Information* table; added ground connections to the N.C. pin in the Typical Operating Circuit.	1
		Added "noncondensing" to operating temperature range; changed V_{PF} MIN from 2.35V to 2.45V.	2
		Added aging offset specification.	3
		Relabeled TOC4.	7
		Added arrow showing input on X1 in the *Block Diagram*.	8
		Updated pin descriptions for V_{CC} and V_{BAT}.	9
		Added the I2C Interface section.	10
		Figure 1: Added sign bit to aging and temperature registers; added MSB and LSB.	11
		Corrected title for rate select bits frequency table.	13
		Added note that frequency stability over temperature spec is with aging offset register = 00h; changed bit 7 from Data to Sign (Crystal Aging Offset Register).	14
		Changed bit 7 from Data to Sign (Temperature Register); correct pin definitions in *I2C Serial Data Bus* section.	15
		Modified the *Handing*, *PC Board Layout*, and *Assembly* section to refer to J-STD-020 for reflow profiles for lead-free and leaded packages.	17
3	11/05	Changed lead-free packages to RoHS-compliant packages.	1
4	10/06	Changed $\overline{RST}$ and UL bullets in *Features*.	1
		Changed EC condition "V_{CC} > V_{BAT}" to "V_{CC} = Active Supply (see Table 1)."	2, 3
		Modified Note 12 to correct t_{REC} operation.	6
		Added various conditions text to TOCs 1, 2, and 3.	7
		Added text to pin descriptions for 32kHz, V_{CC}, and $\overline{RST}$.	9
		Table 1: Changed column heading "Powered By" to "Active Supply"; changed "applied" to "exceeds V_{PF}" in the *Power Control* section.	10
		Indicated BBSQW applies to both SQW and interrupts; simplified temp convert description (bit 5); added "output" to $\overline{INT}$/SQW (bit 2).	13
		Changed the *Crystal Aging* section to the *Aging Offset* section; changed "this bit indicates" to "this bit controls" for the enable 32kHz output bit.	14
5	4/08	Added Warning note to EC table notes; updated Note 12.	6
		Updated the *Typical Operating Characteristics* graphs.	7
		In the *Power Control* section, added information about the POR state of the time and date registers; in the *Real-Time Clock* section, added to the description of the RST function.	10
		In Figure 1, corrected the months date range for 04h from 00–31 to 01–31.	11

Revision History (continued)

REVISION NUMBER	REVISION DATE	DESCRIPTION	PAGES CHANGED
6	10/08	Updated the *Typical Operating Circuit*.	1
		Removed the V_{PU} parameter from the *Recommended DC Operating Conditions* table and added verbiage about the pullup to the *Pin Description* table for $\overline{INT}$/SQW, SDA, and SCL.	2, 9
		Added the Delta Time and Frequency vs. Temperature graph in the *Typical Operating Characteristics* section.	7
		Updated the *Block Diagram*.	8
		Added the *V_{BAT} Operation* section, improved some sections of text for the *32kHz TCXO* and *Pushbutton Reset Function* sections.	10
		Added the register bit POR values to the register tables.	13, 14, 15
		Updated the *Aging Offset* and *Temperature Registers (11h–12h)* sections.	14, 15
		Updated the I2C timing diagrams (Figures 3, 4, and 5).	16, 17
7	3/10	Removed the “S” from the top mark in the *Ordering Information* table and the *Pin Configuration* to match the packaging engineering marking specification.	1, 18
8	7/10	Updated the *Typical Operating Circuit*; removed the “Top Mark” column from the *Ordering Information*; in the *Absolute Maximum Ratings* section, added the theta-JA and theta-JC thermal resistances and Note 1, and changed the soldering temperature to +260°C (lead(Pb)-free) and +240°C (leaded); updated the functional description of the V_{BAT} pin in the *Pin Description*; changed the timekeeping registers 02h, 09h, and 0Ch to “20 Hour” in Bit 5 of Figure 1; updated the BBSQW bit description in the *Control Register (0Eh)* section; added the land pattern no. to the *Package Information* table.	1, 2, 3, 4, 6, 9, 11, 12, 13, 18
9	1/13	Updated *Absolute Maximum Ratings*, and last paragraph in *Power Control* section	2, 10
10	3/15	Revised *Benefits and Features* section.	1

General Description

The DS3231 is a low-cost, extremely accurate I2C real-time clock (RTC) with an integrated temperature-compensated crystal oscillator (TCXO) and crystal. The device incorporates a battery input, and maintains accurate timekeeping when main power to the device is interrupted. The integration of the crystal resonator enhances the long-term accuracy of the device as well as reduces the piece-part count in a manufacturing line. The DS3231 is available in commercial and industrial temperature ranges, and is offered in a 16-pin, 300-mil SO package.

The RTC maintains seconds, minutes, hours, day, date, month, and year information. The date at the end of the month is automatically adjusted for months with fewer than 31 days, including corrections for leap year. The clock operates in either the 24-hour or 12-hour format with an $\overline{AM}$/PM indicator. Two programmable time-of-day alarms and a programmable square-wave output are provided. Address and data are transferred serially through an I2C bidirectional bus.

A precision temperature-compensated voltage reference and comparator circuit monitors the status of V_{CC} to detect power failures, to provide a reset output, and to automatically switch to the backup supply when necessary. Additionally, the $\overline{RST}$ pin is monitored as a pushbutton input for generating a µP reset.

Benefits and Features

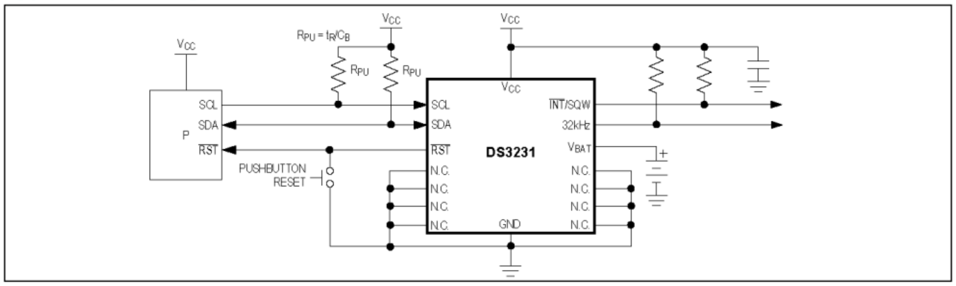
- Highly Accurate RTC Completely Manages All Timekeeping Functions
  - Real-Time Clock Counts Seconds, Minutes, Hours, Date of the Month, Month, Day of the Week, and Year, with Leap-Year Compensation Valid Up to 2100
  - Accuracy ±2ppm from 0°C to +40°C
  - Accuracy ±3.5ppm from -40°C to +85°C
  - Digital Temp Sensor Output: ±3°C Accuracy
  - Register for Aging Trim
  - $\overline{RST}$ Output/Pushbutton Reset Debounce Input
  - Two Time-of-Day Alarms
  - Programmable Square-Wave Output Signal
- Simple Serial Interface Connects to Most Microcontrollers
  - Fast (400kHz) I2C Interface
- Battery-Backup Input for Continuous Timekeeping
  - Low Power Operation Extends Battery-Backup Run Time
  - 3.3V Operation
- Operating Temperature Ranges: Commercial (0°C to +70°C) and Industrial (-40°C to +85°C)
- Underwriters Laboratories® (UL) Recognized

Applications

- Servers
- Telematics
- Utility Power Meters
- GPS

Ordering Information and Pin Configuration appear at end of data sheet.

Typical Operating Circuit



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19-5170; Rev 10; 3/15

Absolute Maximum Ratings

Voltage Range on Any Pin Relative to Ground ....-0.3V to +6.0V
Junction-to-Ambient Thermal Resistance (θ_{JA}) (Note 1) 73°C/W
Junction-to-Case Thermal Resistance (θ_{JC}) (Note 1) ....23°C/W
Operating Temperature Range
DS3231S ....0°C to +70°C
DS3231SN .... -40°C to +85°C
Junction Temperature .... +125°C
Storage Temperature Range .... -40°C to +85°C
Lead Temperature (soldering, 10s) .... +260°C
Soldering Temperature (reflow, 2 times max) .... +260°C
(see the *Handling, PCB Layout, and Assembly* section)

Note 1: Package thermal resistances were obtained using the method described in JEDEC specification JESD51-7, using a four-layer board. For detailed information on package thermal considerations, refer to www.maximintegrated.com/thermal-tutorial.

Stresses beyond those listed under "Absolute Maximum Ratings" may cause permanent damage to the device. These are stress ratings only, and functional operation of the device at these or any other conditions beyond those indicated in the operational sections of the specifications is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.

Recommended Operating Conditions

($T_A = T_{MIN}$ to T_{MAX}, unless otherwise noted.) (Notes 2, 3)

PARAMETER	SYMBOL	CONDITIONS	MIN	TYP	MAX	UNITS
Supply Voltage	V_{CC}		2.3	3.3	5.5	V
	V_{BAT}		2.3	3.0	5.5	V
Logic 1 Input SDA, SCL	V_{IH}		0.7 x V_{CC}		V_{CC} + 0.3	V
Logic 0 Input SDA, SCL	V_{IL}		-0.3		0.3 x V_{CC}	V

Electrical Characteristics

(V_{CC} = 2.3V to 5.5V, V_{CC} = Active Supply (see Table 1), $T_A = T_{MIN}$ to T_{MAX}, unless otherwise noted.) (Typical values are at V_{CC} = 3.3V, V_{BAT} = 3.0V, and T_A = +25°C, unless otherwise noted.) (Notes 2, 3)

PARAMETER	SYMBOL	CONDITIONS		MIN	TYP	MAX	UNITS
Active Supply Current	I_{CCA}	(Notes 4, 5)	V_{CC} = 3.63V			200	µA
			V_{CC} = 5.5V			300	
Standby Supply Current	I_{CCS}	I2C bus inactive, 32kHz output on, SQW output off (Note 5)	V_{CC} = 3.63V			110	µA
			V_{CC} = 5.5V			170	
Temperature Conversion Current	$I_{CCSCONV}$	I2C bus inactive, 32kHz output on, SQW output off	V_{CC} = 3.63V			575	µA
			V_{CC} = 5.5V			650	
Power-Fail Voltage	V_{PF}			2.45	2.575	2.70	V
Logic 0 Output, 32kHz, $\overline{INT}$/SQW, SDA	V_{OL}	I_{OL} = 3mA				0.4	V
Logic 0 Output, $\overline{RST}$	V_{OL}	I_{OL} = 1mA				0.4	V
Output Leakage Current 32kHz, $\overline{INT}$/SQW, SDA	I_{LO}	Output high impedance		-1	0	+1	µA
Input Leakage SCL	I_{LI}			-1		+1	µA
$\overline{RST}$ Pin I/O Leakage	I_{OL}	$\overline{RST}$ high impedance (Note 6)		-200		+10	µA
V_{BAT} Leakage Current (V_{CC} Active)	I_{BATLKG}				25	100	nA

Electrical Characteristics (continued)

(V_{CC} = 2.3V to 5.5V, V_{CC} = Active Supply (see Table 1), $T_A = T_{MIN}$ to T_{MAX}, unless otherwise noted.) (Typical values are at V_{CC} = 3.3V, V_{BAT} = 3.0V, and T_A = +25°C, unless otherwise noted.) (Notes 2, 3)

PARAMETER	SYMBOL	CONDITIONS		MIN	TYP	MAX	UNITS
Output Frequency	f_{OUT}	V_{CC} = 3.3V or V_{BAT} = 3.3V			32.768		kHz
Frequency Stability vs. Temperature (Commercial)	$\Delta f/f_{OUT}$	V_{CC} = 3.3V or V_{BAT} = 3.3V, aging offset = 00h	0°C to +40°C			±2	ppm
			>40°C to +70°C			±3.5	
Frequency Stability vs. Temperature (Industrial)	$\Delta f/f_{OUT}$	V_{CC} = 3.3V or V_{BAT} = 3.3V, aging offset = 00h	-40°C to <0°C			±3.5	ppm
			0°C to +40°C			±2	
			>40°C to +85°C			±3.5	
Frequency Stability vs. Voltage	Δf/V				1		ppm/V
Trim Register Frequency Sensitivity per LSB	Δf/LSB	Specified at:	-40°C		0.7		ppm
			+25°C		0.1		
			+70°C		0.4		
			+85°C		0.8		
Temperature Accuracy	Temp	V_{CC} = 3.3V or V_{BAT} = 3.3V		-3		+3	°C
Crystal Aging	$\Delta f/f_O$	After reflow, not production tested	First year		±1.0		ppm
			0–10 years		±5.0		

Electrical Characteristics

(**V_{CC} = 0V, V_{BAT} = 2.3V to 5.5V**, $T_A = T_{MIN}$ to T_{MAX}, unless otherwise noted.) (Note 2)

PARAMETER	SYMBOL	CONDITIONS		MIN	TYP	MAX	UNITS
Active Battery Current	I_{BATA}	$\overline{EOSC}$ = 0, BBSQW = 0, SCL = 400kHz (Note 5)	V_{BAT} = 3.63V			70	µA
			V_{BAT} = 5.5V			150	
Timekeeping Battery Current	I_{BATT}	$\overline{EOSC}$ = 0, BBSQW = 0, EN32kHz = 1, SCL = SDA = 0V or SCL = SDA = V_{BAT} (Note 5)	V_{BAT} = 3.63V		0.84	3.0	µA
			V_{BAT} = 5.5V		1.0	3.5	
Temperature Conversion Current	I_{BATTC}	$\overline{EOSC}$ = 0, BBSQW = 0, SCL = SDA = 0V or SCL = SDA = V_{BAT}	V_{BAT} = 3.63V			575	µA
			V_{BAT} = 5.5V			650	
Data-Retention Current	I_{BATTDR}	$\overline{EOSC}$ = 1, SCL = SDA = 0V, +25°C				100	nA

AC Electrical Characteristics

($V_{CC} = V_{CC(MIN)}$ to $V_{CC(MAX)}$ or $V_{BAT} = V_{BAT(MIN)}$ to $V_{BAT(MAX)}$, $V_{BAT} > V_{CC}$, $T_A = T_{MIN}$ to T_{MAX}, unless otherwise noted.) (Note 2)

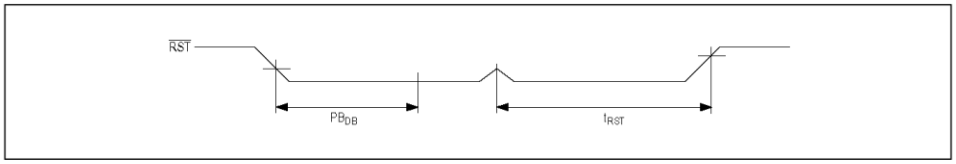
PARAMETER	SYMBOL	CONDITIONS	MIN	TYP	MAX	UNITS
SCL Clock Frequency	f_{SCL}	Fast mode	100		400	kHz
		Standard mode	0		100	
Bus Free Time Between STOP and START Conditions	t_{BUF}	Fast mode	1.3			µs
		Standard mode	4.7			
Hold Time (Repeated) START Condition (Note 7)	$t_{HD:STA}$	Fast mode	0.6			µs
		Standard mode	4.0			
Low Period of SCL Clock	t_{LOW}	Fast mode	1.3			µs
		Standard mode	4.7			
High Period of SCL Clock	t_{HIGH}	Fast mode	0.6			µs
		Standard mode	4.0			
Data Hold Time (Notes 8, 9)	$t_{HD:DAT}$	Fast mode	0		0.9	µs
		Standard mode	0		0.9	
Data Setup Time (Note 10)	$t_{SU:DAT}$	Fast mode	100			ns
		Standard mode	250			
START Setup Time	$t_{SU:STA}$	Fast mode	0.6			µs
		Standard mode	4.7			
Rise Time of Both SDA and SCL Signals (Note 11)	t_R	Fast mode	$20 + 0.1C_B$		300	ns
		Standard mode			1000	
Fall Time of Both SDA and SCL Signals (Note 11)	t_F	Fast mode	$20 + 0.1C_B$		300	ns
		Standard mode			300	
Setup Time for STOP Condition	$t_{SU:STO}$	Fast mode	0.6			µs
		Standard mode	4.7			
Capacitive Load for Each Bus Line	C_B	(Note 11)			400	pF
Capacitance for SDA, SCL	$C_{I/O}$			10		pF
Pulse Width of Spikes That Must Be Suppressed by the Input Filter	t_{SP}			30		ns
Pushbutton Debounce	PB_{DB}			250		ms
Reset Active Time	t_{RST}			250		ms
Oscillator Stop Flag (OSF) Delay	t_{OSF}	(Note 12)		100		ms
Temperature Conversion Time	t_{CONV}			125	200	ms

Power-Switch Characteristics

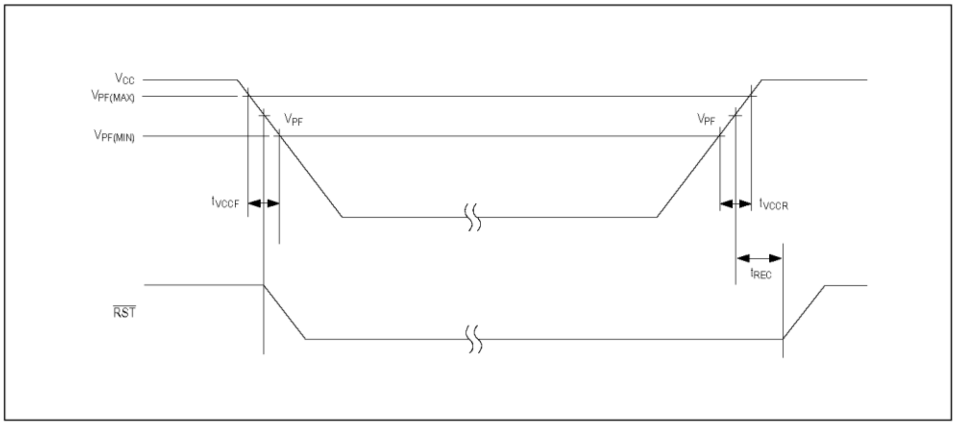
($T_A = T_{MIN}$ to T_{MAX})

PARAMETER	SYMBOL	CONDITIONS	MIN	TYP	MAX	UNITS
V_{CC} Fall Time; $V_{PF(MAX)}$ to $V_{PF(MIN)}$	t_{VCCF}		300			µs
V_{CC} Rise Time; $V_{PF(MIN)}$ to $V_{PF(MAX)}$	t_{VCCR}		0			µs
Recovery at Power-Up	t_{REC}	(Note 13)		250	300	ms

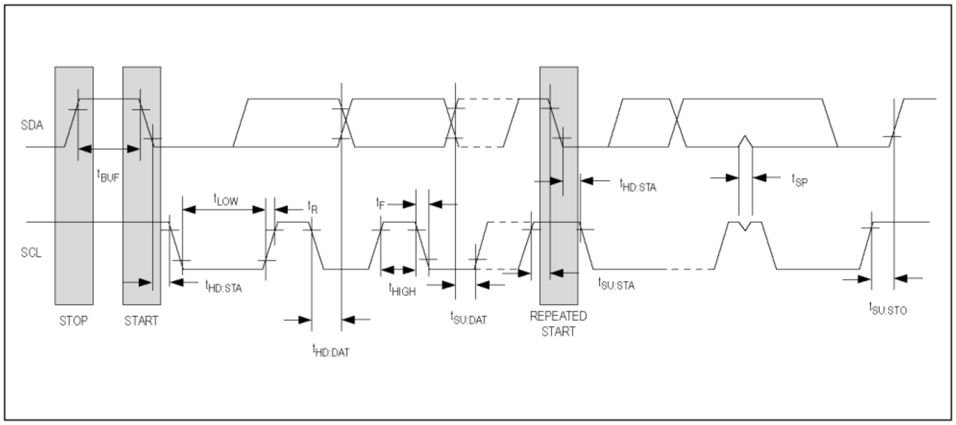
Pushbutton Reset Timing



Power-Switch Timing



Data Transfer on I2C Serial Bus



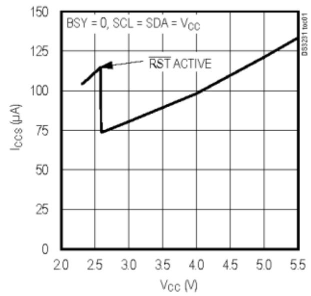
WARNING: Negative undershoots below -0.3V while the part is in battery-backed mode may cause loss of data.

Note 2: Limits at -40°C are guaranteed by design and not production tested.
Note 3: All voltages are referenced to ground.
Note 4: I_{CCA}—SCL clocking at max frequency = 400kHz.
Note 5: Current is the averaged input current, which includes the temperature conversion current.
Note 6: The $\overline{RST}$ pin has an internal 50kΩ (nominal) pullup resistor to V_{CC}.
Note 7: After this period, the first clock pulse is generated.
Note 8: A device must internally provide a hold time of at least 300ns for the SDA signal (referred to the $V_{IH(MIN)}$ of the SCL signal) to bridge the undefined region of the falling edge of SCL.
Note 9: The maximum $t_{HD:DAT}$ needs only to be met if the device does not stretch the low period (t_{LOW}) of the SCL signal.
Note 10: A fast-mode device can be used in a standard-mode system, but the requirement $t_{SU:DAT} \geq$ 250ns must then be met. This is automatically the case if the device does not stretch the low period of the SCL signal. If such a device does stretch the low period of the SCL signal, it must output the next data bit to the SDA line $t_{R(MAX)} + t_{SU:DAT}$ = 1000 + 250 = 1250ns before the SCL line is released.
Note 11: C_B—total capacitance of one bus line in pF.
Note 12: The parameter t_{OSF} is the period of time the oscillator must be stopped for the OSF flag to be set over the voltage range of 0.0V ≤ V_{CC} ≤ $V_{CC(MAX)}$ and 2.3V ≤ V_{BAT} ≤ 3.4V.
Note 13: This delay applies only if the oscillator is enabled and running. If the $\overline{EOSC}$ bit is a 1, t_{REC} is bypassed and $\overline{RST}$ immediately goes high. The state of $\overline{RST}$ does not affect the I2C interface, RTC, or TCXO.

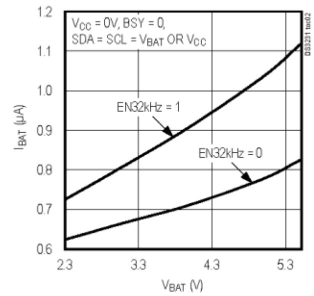
Typical Operating Characteristics

(V_{CC} = +3.3V, T_A = +25°C, unless otherwise noted.)

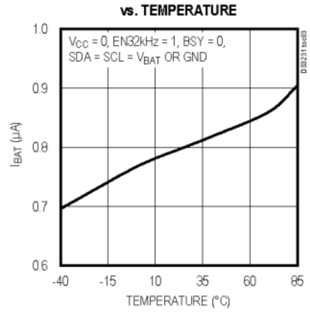
STANDBY SUPPLY CURRENT vs. SUPPLY VOLTAGE



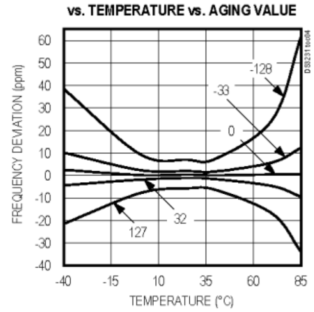
SUPPLY CURRENT vs. SUPPLY VOLTAGE



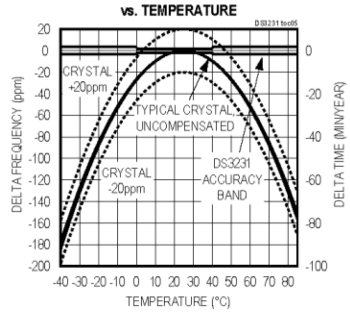
SUPPLY CURRENT vs. TEMPERATURE



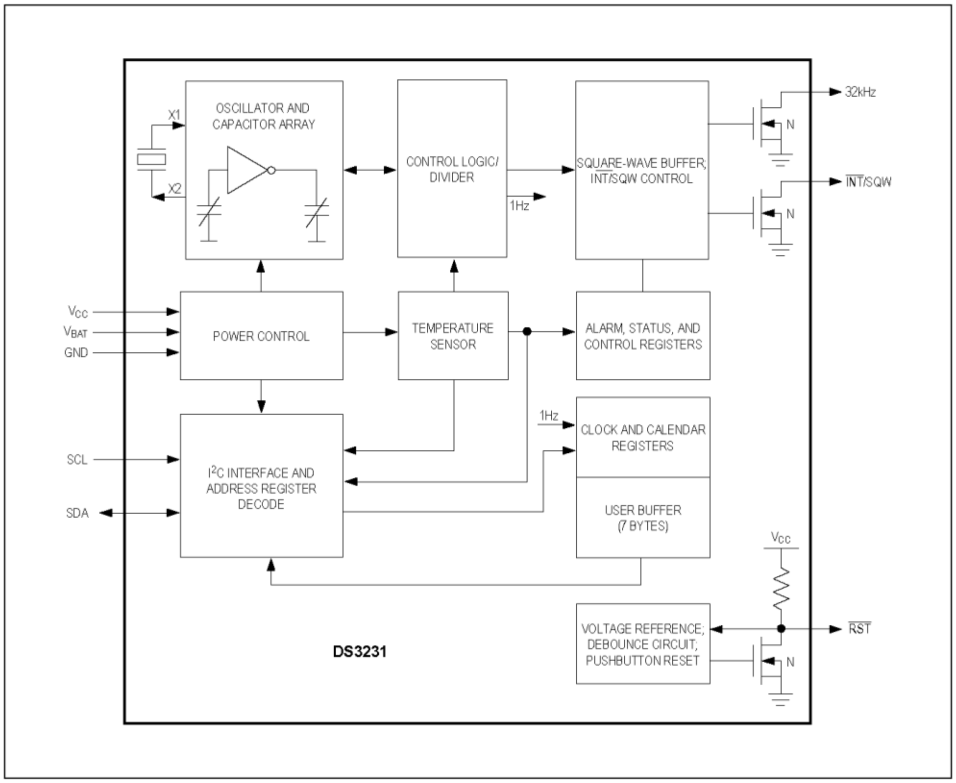
FREQUENCY DEVIATION vs. TEMPERATURE vs. AGING VALUE



DELTA TIME AND FREQUENCY vs. TEMPERATURE



Block Diagram



Pin Description

PIN	NAME	FUNCTION
1	32kHz	32kHz Output. This open-drain pin requires an external pullup resistor. When enabled, the output operates on either power supply. It may be left open if not used.
2	V_{CC}	DC Power Pin for Primary Power Supply. This pin should be decoupled using a 0.1µF to 1.0µF capacitor. If not used, connect to ground.
3	$\overline{INT}$/SQW	Active-Low Interrupt or Square-Wave Output. This open-drain pin requires an external pullup resistor connected to a supply at 5.5V or less. This multifunction pin is determined by the state of the INTCN bit in the Control Register (0Eh). When INTCN is set to logic 0, this pin outputs a square wave and its frequency is determined by RS2 and RS1 bits. When INTCN is set to logic 1, then a match between the timekeeping registers and either of the alarm registers activates the $\overline{INT}$/SQW pin (if the alarm is enabled). Because the INTCN bit is set to logic 1 when power is first applied, the pin defaults to an interrupt output with alarms disabled. The pullup voltage can be up to 5.5V, regardless of the voltage on V_{CC}. If not used, this pin can be left unconnected.
4	$\overline{RST}$	Active-Low Reset. This pin is an open-drain input/output. It indicates the status of V_{CC} relative to the V_{PF} specification. As V_{CC} falls below V_{PF}, the $\overline{RST}$ pin is driven low. When V_{CC} exceeds V_{PF}, for t_{RST}, the $\overline{RST}$ pin is pulled high by the internal pullup resistor. The active-low, open-drain output is combined with a debounced pushbutton input function. This pin can be activated by a pushbutton reset request. It has an internal 50kΩ nominal value pullup resistor to V_{CC}. No external pullup resistors should be connected. If the oscillator is disabled, t_{REC} is bypassed and $\overline{RST}$ immediately goes high.
5–12	N.C.	No Connection. Must be connected to ground.
13	GND	Ground
14	V_{BAT}	Backup Power-Supply Input. When using the device with the V_{BAT} input as the primary power source, this pin should be decoupled using a 0.1µF to 1.0µF low-leakage capacitor. When using the device with the V_{BAT} input as the backup power source, the capacitor is not required. If V_{BAT} is not used, connect to ground. The device is UL recognized to ensure against reverse charging when used with a primary lithium battery. Go to **www.maximintegrated.com/qa/info/ul**.
15	SDA	Serial Data Input/Output. This pin is the data input/output for the I2C serial interface. This open-drain pin requires an external pullup resistor. The pullup voltage can be up to 5.5V, regardless of the voltage on V_{CC}.
16	SCL	Serial Clock Input. This pin is the clock input for the I2C serial interface and is used to synchronize data movement on the serial interface. Up to 5.5V can be used for this pin, regardless of the voltage on V_{CC}.

Detailed Description

The DS3231 is a serial RTC driven by a temperature-compensated 32kHz crystal oscillator. The TCXO provides a stable and accurate reference clock, and maintains the RTC to within ±2 minutes per year accuracy from -40°C to +85°C. The TCXO frequency output is available at the 32kHz pin. The RTC is a low-power clock/calendar with two programmable time-of-day alarms and a programmable square-wave output. The $\overline{INT}$/SQW provides either an interrupt signal due to alarm conditions or a square-wave output. The clock/calendar provides seconds, minutes, hours, day, date, month, and year information. The date at the end of the month is automatically adjusted for months with fewer than 31 days, including corrections for leap year. The clock operates in either the 24-hour or 12-hour format with an $\overline{AM}$/PM indicator. The internal registers are accessible though an I2C bus interface.

A temperature-compensated voltage reference and comparator circuit monitors the level of V_{CC} to detect power failures and to automatically switch to the backup supply when necessary. The $\overline{RST}$ pin provides an external pushbutton function and acts as an indicator of a power-fail event.

Operation

The block diagram shows the main elements of the DS3231. The eight blocks can be grouped into four functional groups: TCXO, power control, pushbutton function, and RTC. Their operations are described separately in the following sections.

32kHz TCXO

The temperature sensor, oscillator, and control logic form the TCXO. The controller reads the output of the on-chip temperature sensor and uses a lookup table to determine the capacitance required, adds the aging correction in AGE register, and then sets the capacitance selection registers. New values, including changes to the AGE register, are loaded only when a change in the temperature value occurs, or when a user-initiated temperature conversion is completed. Temperature conversion occurs on initial application of V_{CC} and once every 64 seconds afterwards.

Power Control

This function is provided by a temperature-compensated voltage reference and a comparator circuit that monitors the V_{CC} level. When V_{CC} is greater than V_{PF}, the part is powered by V_{CC}. When V_{CC} is less than V_{PF} but greater than V_{BAT}, the DS3231 is powered by V_{CC}. If V_{CC} is less than V_{PF} and is less than V_{BAT}, the device is powered by V_{BAT}. See Table 1.

Table 1. Power Control

SUPPLY CONDITION	ACTIVE SUPPLY
$V_{CC} < V_{PF}$, $V_{CC} < V_{BAT}$	V_{BAT}
$V_{CC} < V_{PF}$, $V_{CC} > V_{BAT}$	V_{CC}
$V_{CC} > V_{PF}$, $V_{CC} < V_{BAT}$	V_{CC}
$V_{CC} > V_{PF}$, $V_{CC} > V_{BAT}$	V_{CC}

To preserve the battery, the first time V_{BAT} is applied to the device, the oscillator will not start up until V_{CC} exceeds V_{PF}, or until a valid I2C address is written to the part. Typical oscillator startup time is less than one second. Approximately 2 seconds after V_{CC} is applied, or a valid I2C address is written, the device makes a temperature measurement and applies the calculated correction to the oscillator. Once the oscillator is running, it continues to run as long as a valid power source is available (V_{CC} or V_{BAT}), and the device continues to measure the temperature and correct the oscillator frequency every 64 seconds.

On the first application of power (V_{CC}) or when a valid I2C address is written to the part (V_{BAT}), the time and date registers are reset to 01/01/00 01 00:00:00 (DD/MM/YY DOW HH:MM:SS).

V_{BAT} Operation

There are several modes of operation that affect the amount of V_{BAT} current that is drawn. While the device is powered by V_{BAT} and the serial interface is active, active battery current, I_{BATA}, is drawn. When the serial interface is inactive, timekeeping current (I_{BATT}), which includes the averaged temperature conversion current, I_{BATTC}, is used (refer to Application Note 3644: *Power Considerations for Accurate Real-Time Clocks* for details). Temperature conversion current, I_{BATTC}, is specified since the system must be able to support the periodic higher current pulse and still maintain a valid voltage level. Data retention current, I_{BATTDR}, is the current drawn by the part when the oscillator is stopped ($\overline{EOSC}$ = 1). This mode can be used to minimize battery requirements for times when maintaining time and date information is not necessary, e.g., while the end system is waiting to be shipped to a customer.

Pushbutton Reset Function

The DS3231 provides for a pushbutton switch to be connected to the $\overline{RST}$ output pin. When the DS3231 is not in a reset cycle, it continuously monitors the $\overline{RST}$ signal for a low going edge. If an edge transition is detected, the DS3231 debounces the switch by pulling the $\overline{RST}$ low. After the internal timer has expired (PB_{DB}), the DS3231 continues to monitor the $\overline{RST}$ line. If the line is still low, the DS3231 continuously monitors the line looking for a rising edge. Upon detecting release, the DS3231 forces the $\overline{RST}$ pin low and holds it low for t_{RST}.

$\overline{RST}$ is also used to indicate a power-fail condition. When V_{CC} is lower than V_{PF}, an internal power-fail signal is generated, which forces the $\overline{RST}$ pin low. When V_{CC} returns to a level above V_{PF}, the $\overline{RST}$ pin is held low for approximately 250ms (t_{REC}) to allow the power supply to stabilize. If the oscillator is not running (see the *Power Control* section) when V_{CC} is applied, t_{REC} is bypassed and $\overline{RST}$ immediately goes high. Assertion of the $\overline{RST}$ output, whether by pushbutton or power-fail detection, does not affect the internal operation of the DS3231.

Real-Time Clock

With the clock source from the TCXO, the RTC provides seconds, minutes, hours, day, date, month, and year information. The date at the end of the month is automatically adjusted for months with fewer than 31 days, including corrections for leap year. The clock operates in either the 24-hour or 12-hour format with an $\overline{AM}$/PM indicator.

The clock provides two programmable time-of-day alarms and a programmable square-wave output. The $\overline{INT}$/SQW pin either generates an interrupt due to alarm condition or outputs a square-wave signal and the selection is controlled by the bit INTCN.

LED COLOR

SK6812

Technical Data Sheet

Product Overview

SK6812 is a set of smart control circuit and a light emitting circuit in one of the controlled LED source. The outer type is the same with a 5050LED chip, each element is a pixel. Pixels contained within the intelligent digital interface data latch signal shaping amplification circuit, power supply circuit, a built-in constant current circuit, high precision RC oscillator, the output is driven by the patented PWM technology, effectively guarantee the pixels in the color of the light high consistency.

Data protocol using unipolar NRZ communication mode, the pixel is reset after the end of DIN, accept the data transmitted from the controller to the 24bit, the first to send data by the first pixel to pixel extraction, internal data latch, the remaining data after the internal plastic the processing circuit after shaping amplification through the DO port output began to turn to the next cascade of pixels, each pixel through a transmission signal, reduce. Pixel using automatic shaping forwarding technology, makes the number of cascade without signal transmission limit of the pixel, only limited signal transmission speed. The

LED has a low driving voltage, environmental protection and energy saving, high brightness, scattering angle, good consistency, low power, long life and so on. The control circuit is integrated in the LED above, more simple circuit, small volume, easy installation.

Main Application Field:

● Full color LED string light, LED full color module, LED super hard and soft lights, LED guardrail tube, LED appearance / scene lighting

● LED point light, LED pixel screen, LED shaped screen, a variety of electronic products, electrical equipment etc..

LED COLOR

SK6812

Technical Data Sheet

Description:

● Top SMD internal integrated high quality external control line serial cascade constant current IC;

● control circuit and the RGB chip in SMD 5050 components, to form a complete control of pixel, color mixing uniformity and consistency;

●built-in data shaping circuit, a pixel signal is received after wave shaping and output waveform distortion will not guarantee a line;

●The built-in power on reset and reset circuit, the power does not work;

●gray level adjusting circuit (256 level gray scale adjustable);

● red drive special treatment, color balance;

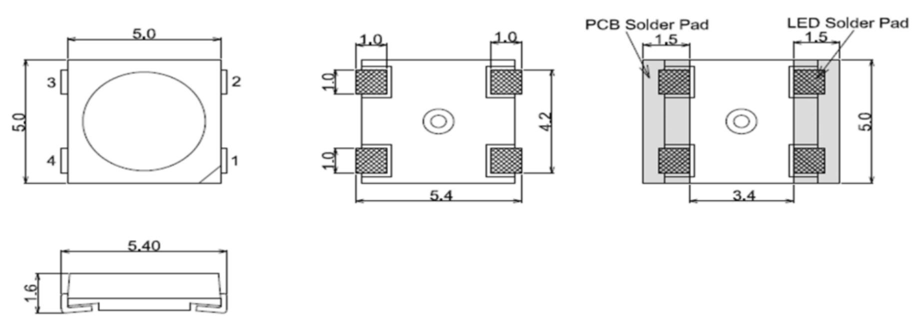
● line data transmission;

● plastic forward strengthening technology, the transmission distance between two points over 10M;

●data transmission frequency up to 800Kbps, when the refresh rate of 30 frames per second, a cascade of not less than 1024;

● built-in powerpolarity protection module, powerpolarity will not damage.

Mechanical Product Size (unit mm):

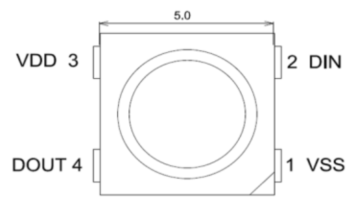


LED COLOR

SK6812

Technical Data Sheet

Mechanical Size and Pin Map (unit mm):



Pin Function:

Item	Symbol	Pin Name	Function description
1	VSS	Ground	The signal and power supply and grounding
2	DIN	Data Input	control signal input data
3	VDD	Power	power supply pin
4	DOUT	Data Output	control signal output data

The electrical parameters (limit parameters, Ta=25 C, VSS=0V):

Parameter	Symbol	Range	Unit
Input voltage	V_{IN}	+5	V
Logic input voltage	V_I	-0.5～VDD+5.5	V
Working temperature	Topt	-40~+85	℃
Storage temperature	Tstg	-50~+150	℃
EST pressure	V_{ESD}	4K	V

The electrical parameters (such as no special instructions, TA=-20 ~ +70 ~ 5.5V C, VDD=4.5, VSS=0V):

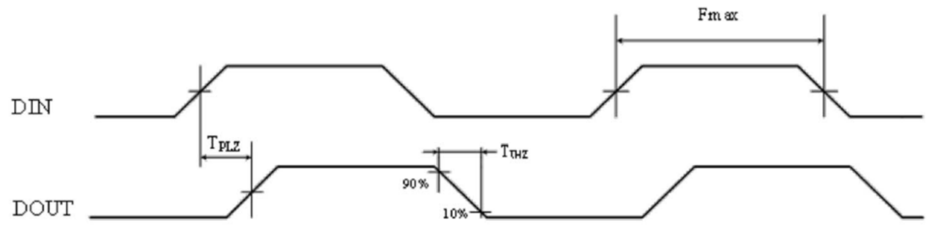
Parmeter	Symbol	Min	Typical	Max	Unit	Test conditions
The chip supply voltage	VDD	---	5.2		V	---
R/G/B port pressure	VDS,MAX	---	---	26	V	---
DOUT drive capability	IDOH	---	49	---	mA	DOUT conect ground, the maximum drive current
	IDOL	---	-50	---	mA	DOUT conect +, the largest current
The signal input flip threshold	VIH	---	3.4	---		VDD=5.0V
	VIL	---	1.6	---		
The frequency of PWM	FPWM	---	1.2	---	KHZ	---
Static power consumption	IDD	---	1	---	mA	---

The dynamic parameters (Ta=25 C):

Parameter	Symbol	Min	Typical	Max	Unit	Test conditions
The speed of data transmission	fDIN	---	800	---	KHZ	The duty ratio of 67% (data 1)
DOUT transmission delay	T_{PLZ}	---	---	500	ns	DIN→DOUT
	T_{PLZ}	---	---	500	ns	

SK6812

Technical Data Sheet



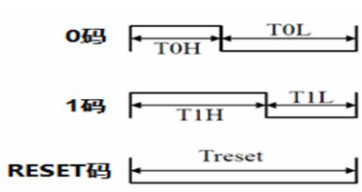
RGB chip characteristic parameters:

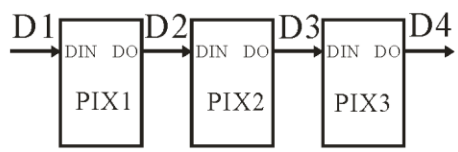
Color	Wavelength(nm)	Luminous intensity(mcd)	Working voltage(v)
Red	620-625	700-1000	2.0-2.2
Green	522.5-525	1500-2200	3.0-3.3
Blue	467.5-470	700-1000	3.0-3.3

The data transmission time (TH+TL=1.25μs±600ns):

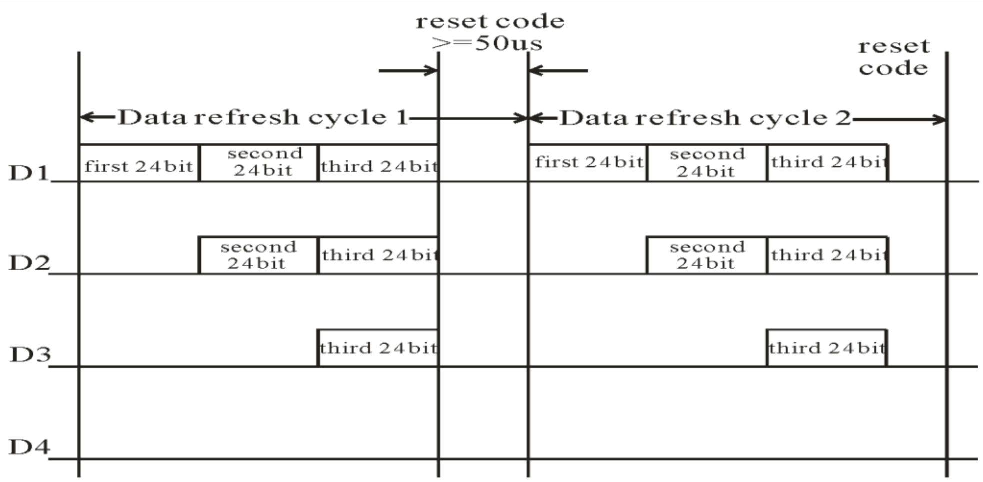
T0H	0 code, high level time	0.3μs	±0.15μs
T1H	1 code, high level time	0.6μs	±0.15μs
T0L	0 code, low level time	0.9μs	±0.15μs
T1L	1 code, low level time	0.6μs	±0.15μs
Trst	Reset code，low level time	80μs	

Timing waveform:





The method of data transmission:



Note: the D1 sends data for MCU, D2, D3, D4 for data forwarding automatic shaping cascade circuit.

The data structure of 24bit:

G7	G6	G5	G4	G3	G2	G1	G0	R7	R6	R5	R4
R3	R2	R1	R0	B7	B6	B5	B4	B3	B2	B1	B0

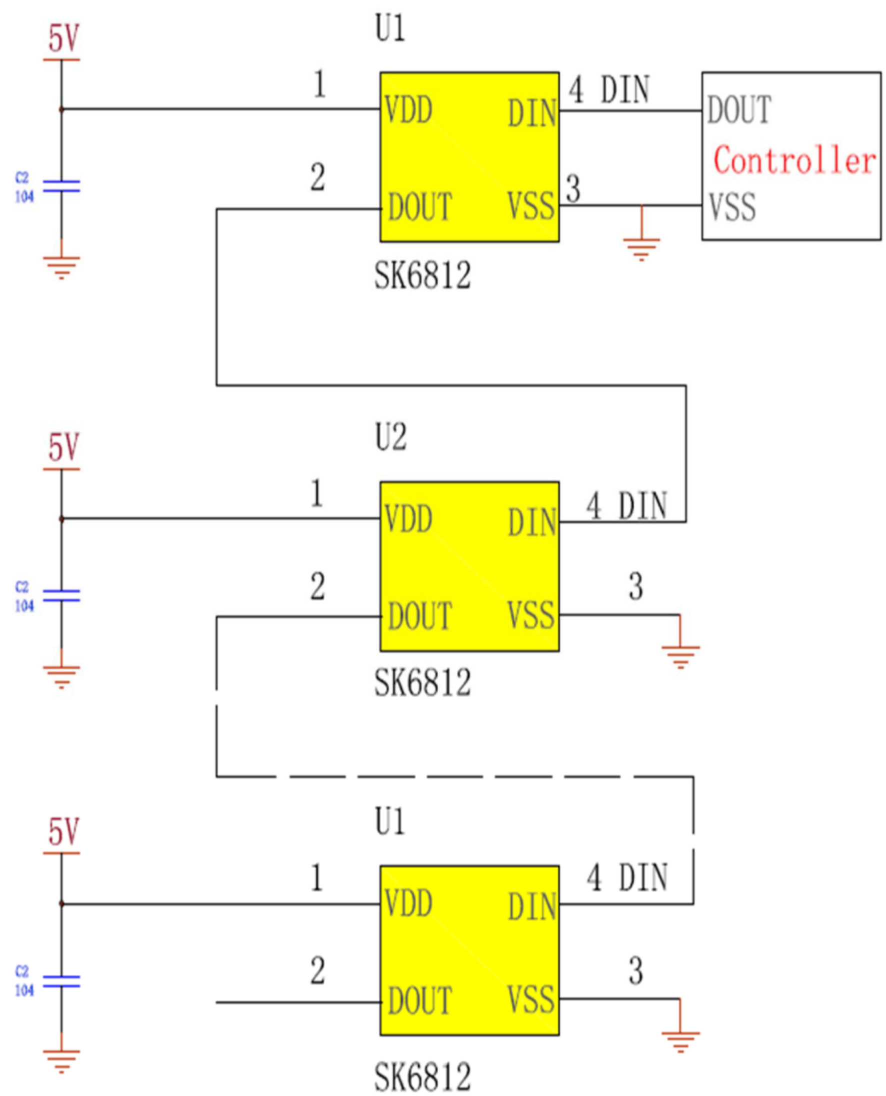
Note: high starting, in order to send data (G7 - G6 - ....B0)

LED COLOR

SK6812

Technical Data Sheet

The typical application circuit:



WS2812

Intelligent control LED integrated light source

Worldsemi

Features and Benefits

- Control circuit and RGB chip are integrated in a package of 5050 components, form a complete control of pixel point.
- Built-in signal reshaping circuit, after wave reshaping to the next driver, ensure wave-form distortion not accumulate.
- Built-in electric reset circuit and power lost reset circuit.
- Each pixel of the three primary color can achieve 256 brightness display, completed 16777216 color full color display, and scan frequency not less than 400Hz/s.
- Cascading port transmission signal by single line.
- Any two point the distance more than 5m transmission signal without any increase circuit.
- When the refresh rate is 30fps, low speed model cascade number are not less than 512 points, high speed mode not less than1024 points.
- Send data at speeds of 800Kbps.
- The color of the light were highly consistent, cost-effective..

Applications

- Full-color module, Full color soft lights a lamp strip.
- LED decorative lighting, Indoor/outdoor LED video irregular screen.

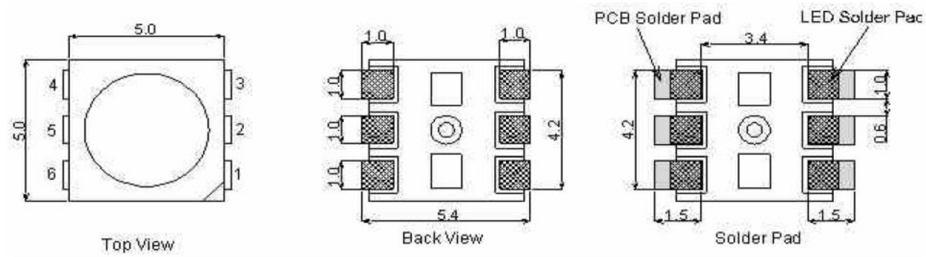
General description

WS2812 is a intelligent control LED light source that the control circuit and RGB chip are integrated in a package of 5050 components. It internal include intelligent digital port data latch and signal reshaping amplif ication drive circuit. Also include a precision internal oscillator and a 12V voltage programmable constant curre -nt control part, effectively ensuring the pixel point light color height consistent.

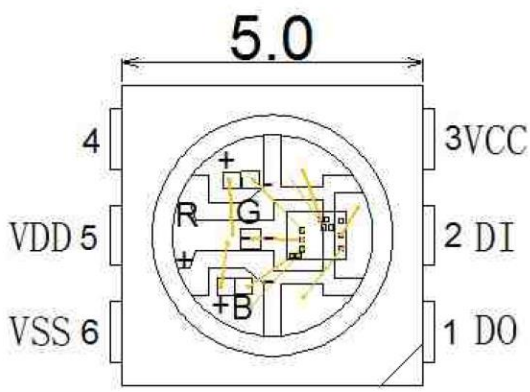
The data transfer protocol use single NZR communication mode. After the pixel power-on reset, the DIN port receive data from controller, the first pixel collect initial 24bit data then sent to the internal data latch, the other data which reshaping by the internal signal reshaping amplification circuit sent to the next cascade pixel through the DO port. After transmission for each pixel，the signal to reduce 24bit. pixel adopt auto resha -ping transmit technology, making the pixel cascade number is not limited the signal transmission, only depend on the speed of signal transmission.

LED with low driving voltage, environmental protection and energy saving, high brightness, scattering angl e is large, good consistency, low power, long life and other advantages. The control chip integrated in LED above becoming more simple circuit, small volume, convenient installation.

Mechanical Dimensions



PIN configuration



PIN function

NO.	Symbol	Function description
1	DOUT	Control data signal output
2	DIN	Control data signal input
3	VCC	Power supply control circuit
4	NC	
5	VDD	Power supply LED
6	VSS	Ground

Absolute Maximum Ratings

Prameter	Symbol	Ratings	Unit
Power supply voltage	V_{CC}	+6.0~+7.0	V
Power supply voltage	V_{DD}	+6.0~+7.0	V
Input voltage	V_I	-0.5～VDD+0.5	V
Operation junction temperature	Topt	-25～+80	℃
Storage temperature range	Tstg	-55~+150	℃

Electrical Characteristics（T_A=-20～+70℃，V_{DD}=4.5～5.5V,V_{SS}=0V,unless otherwise specified）

Prameter	Smybol	conditions	Min	Tpy	Max	Unit
Low voltage output current	I_{OL}	ROUT	——	18.5	——	mA
	I_{dout}	V_O=0.4V，D_{OUT}	10	——	——	mA
Input current	I_I	V_I=V_{DD}/V_{SS}	——	——	±1	µA
Input voltage level	V_{IH}	D_{IN}，SET	0.7V_{DD}	——	——	V
	V_{IL}	D_{IN}，SET	——	——	0.3 V_{DD}	V
Hysteresis voltage	V_H	D_{IN}，SET	——	0.35	——	V

Switching characteristics（T_A=-20～+70℃，V_{DD}=4.5～5.5V,V_{SS}=0V,unless otherwise specified）

Prameter	Symbol	Condition	Min	Tpy	Max	Unit
Operation frequency	*Fosc*2	——	——	800	——	KHz
Transmission delay time	t_{PLZ}	CL=15pF,DIN→DOUT,RL=10KΩ	——	——	300	ns
Fall time	t_{THZ}	CL=300pF,OUTR/OUTG/OUTB	——	——	120	µs
Data transmission rate	F_{MAX}	Duty ratio50%	400	——	——	Kbps
Input capcity	C_I	——	——	——	15	pF

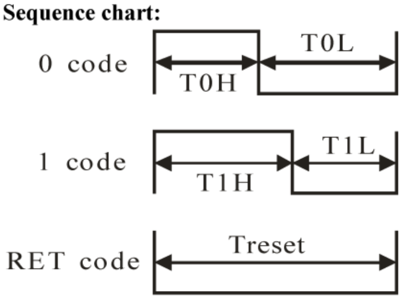
LED characteristic parameter

Emitting color	Wavelength(nm)	Luminous intensity(mcd)	Current(mA)	Voltage(V)
Red	620-630	550-700	20	1.8-2.2
Green	515-530	1100-1400	20	3.0-3.2
Blue	465-475	200-400	20	3.2-3.4

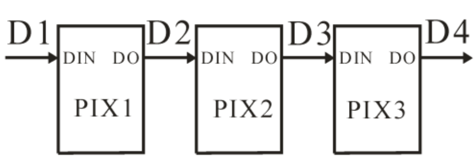
Data transfer time(TH+TL=1.25μs±600ns)

T0H	0 code ,high voltage time	0.35us	±150ns
T1H	1 code ,high voltage time	0.7us	±150ns
T0L	0 code , low voltage time	0.8us	±150ns
T1L	1 code ,low voltage time	0.6us	±150ns
RES	low voltage time	Above 50μs	

Sequence chart:

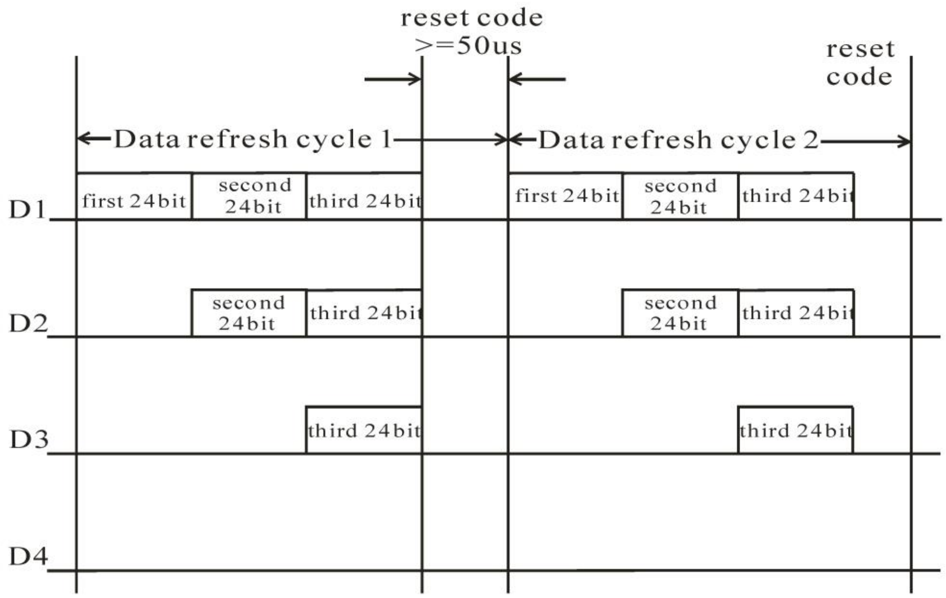


Cascade method:



http://www.world-semi.com

Data transmission method:



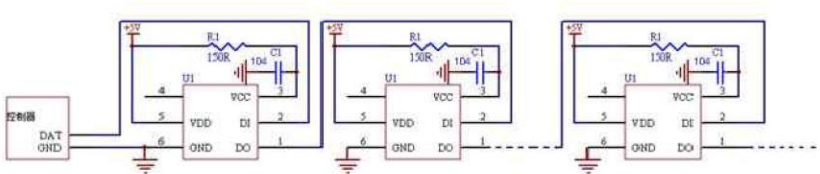
Note: The data of D1 is send by MCU,and D2, D3, D4 through pixel internal reshaping amplification to transmit.

Composition of 24bit data:

G7	G6	G5	G4	G3	G2	G1	G0	R7	R6	R5	R4	R3	R2	R1	R0	B7	B6	B5	B4	B3	B2	B1	B0

Note: Follow the order of GRB to sent data and the high bit sent at first.

Typical application circuit:



MEAN WELL 50W Single Output Switching Power Supply **LRS-50 series**

■ Features

- Universal AC input / Full range
- Withstand 300VAC surge input for 5 second
- No load power consumption<0.2W
- Miniature size and 1U low profile
- High operating temperature up to 70℃
- Protections: Short circuit / Overload / Over voltage
- Cooling by free air convection
- Compliance to IEC/EN 60335-1(PD3) and IEC/EN61558-1, -2-16 for household appliances
- Operating altitude up to 5000 meters (Note.8)
- Withstand 5G vibration test
- High efficiency, long life and high reliability
- LED indicator for power on
- Over voltage category III
- 100% full load burn-in test
- 3 years warranty

■ Applications

- Industrial automation machinery
- Industrial control system
- Mechanical and electrical equipment
- Electronic instruments, equipments or apparatus
- Household appliances

■ Description

LRS-50 series is a 50W single-output enclosed type power supply with 30mm of low profile design. Adopting the full range 85~264VAC input, the entire series provides an output voltage line of 3.3V, 5V, 12V, 15V, 24V, 36V and 48V.

In addition to the high efficiency up to 90%, the design of metallic mesh case enhances the heat dissipation of LRS-50 that the whole series operates from -30℃ through 70℃ under air convection without a fan. Delivering an extremely low no load power consumption (less than 0.2W), it allows the end system to easily meet the worldwide energy requirement. LRS-50 has the complete protection functions and 5G anti-vibration capability; it is complied with the international safety regulations such as TUV EN60950-1, EN60335-1,EN61558-1/-2-16, UL60950-1 and GB4943. LRS-50 series serves as a high price-to-performance power supply solution for various industrial applications.

■ Model Encoding

LRS - 50 - $\boxed{3.3}$

- 3.3 — Output voltage
- 50 — Rated wattage
- LRS — Series name

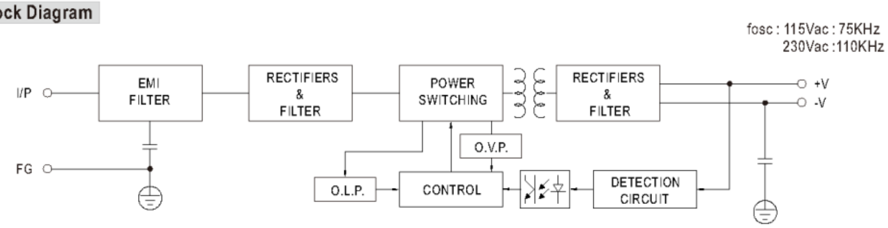
SPECIFICATION

MODEL		LRS-50-3.3	LRS-50-5	LRS-50-12	LRS-50-15	LRS-50-24	LRS-50-36	LRS-50-48
OUTPUT	DC VOLTAGE	3.3V	5V	12V	15V	24V	36V	48V
	RATED CURRENT	10A	10A	4.2A	3.4A	2.2A	1.45A	1.1A
	CURRENT RANGE	0 ~ 10A	0 ~ 10A	0 ~ 4.2A	0 ~ 3.4A	0 ~ 2.2A	0 ~ 1.45A	0 ~ 1.1A
	RATED POWER	33W	50W	50.4W	51W	52.8W	52.2W	52.8W
	RIPPLE & NOISE (max.) Note.2	80mVp-p	80mVp-p	120mVp-p	120mVp-p	150mVp-p	200mVp-p	200mVp-p
	VOLTAGE ADJ. RANGE	2.97 ~ 3.6V	4.5 ~ 5.5V	10.2 ~ 13.8V	13.5 ~ 18V	21.6 ~ 28.8V	32.4 ~ 39.6V	43.2 ~ 52.8V
	VOLTAGE TOLERANCE Note.3	±3.0%	±2.0%	±1.0%	±1.0%	±1.0%	±1.0%	±1.0%
	LINE REGULATION Note.4	±0.5%	±0.5%	±0.5%	±0.5%	±0.5%	±0.5%	±0.5%
	LOAD REGULATION Note.5	±2.0%	±1.0%	±0.5%	±0.5%	±0.5%	±0.5%	±0.5%
	SETUP, RISE TIME	1000ms, 30ms/230VAC 2000ms,30ms/115VAC at full load						
	HOLD UP TIME (Typ.)	30ms/230VAC 12ms/115VAC at full load						
INPUT	VOLTAGE RANGE	85 ~ 264VAC 120 ~ 373VDC						
	FREQUENCY RANGE	47 ~ 63Hz						
	EFFICIENCY (Typ.)	80%	83%	86%	88%	88%	89%	90%
	AC CURRENT (Typ.)	0.95A/115VAC 0.56A/230VAC						
	INRUSH CURRENT (Typ.)	COLD START 45A/230VAC						
	LEAKAGE CURRENT	<0.75mA / 240VAC						
PROTECTION	OVER LOAD	110 ~ 150% rated output power						
		Protection type : Hiccup mode, recovers automatically after fault condition is removed						
	OVER VOLTAGE	3.8 ~ 4.45V	5.9 ~ 7.3V	13.8 ~ 16.2V	18.75 ~ 21.75V	28.8 ~ 33.6V	41.4 ~ 48.6V	55.2 ~ 64.8V
		Protection type : Shut down o/p voltage, re-power on to recover						
ENVIRONMENT	WORKING TEMP.	-30 ~ +70℃ (Refer to "Derating Curve")						
	WORKING HUMIDITY	20 ~ 90% RH non-condensing						
	STORAGE TEMP., HUMIDITY	-40 ~ +85℃, 10 ~ 95% RH non-condensing						
	TEMP. COEFFICIENT	±0.03%/℃ (0 ~ 50℃)						
	VIBRATION	10 ~ 500Hz, 5G 10min./1cycle, 60min. each along X, Y, Z axes						
	OVER VOLTAGE CATEGORY	III; Compliance to EN61558, EN50178, EN60664-1, EN62477-1; altitude up to 2000 meters						
SAFETY & EMC (Note 9)	SAFETY STANDARDS	UL60950-1, TUV EN60950-1, EN60335-1, EN61558-1/-2-16, CCC GB4943.1, BSMI CNS14336-1, EAC TP TC 004, AS/NZS 60950.1(by CB) approved						
	WITHSTAND VOLTAGE	I/P-O/P:4KVAC I/P-FG:2KVAC O/P-FG:1.25KVAC						
	ISOLATION RESISTANCE	I/P-O/P, I/P-FG, O/P-FG:100M Ohms / 500VDC / 25℃ / 70% RH						
	EMC EMISSION	Compliance to EN55032 (CISPR32) Class B, EN55014, EN61000-3-2,-3, GB/T 9254, BSMI CNS13438, EAC TP TC 020						
	EMC IMMUNITY	Compliance to EN61000-4-2,3,4,5,6,8,11, EN61000-6-2 (EN50082-2), heavy industry level, criteria A, EAC TP TC 020						
OTHERS	MTBF	645K hrs min. MIL-HDBK-217F (25℃)						
	DIMENSION	99*82*30mm (L*W*H)						
	PACKING	0.23Kg; 60pcs/14.8Kg/0.88CUFT						

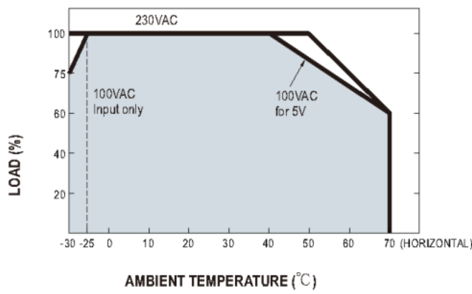
NOTE

1. All parameters NOT specially mentioned are measured at 230VAC input, rated load and 25℃ of ambient temperature.
2. Ripple & noise are measured at 20MHz of bandwidth by using a 12" twisted pair-wire terminated with a 0.1uf & 47uf parallel capacitor.
3. Tolerance : includes set up tolerance, line regulation and load regulation.
4. Line regulation is measured from low line to high line at rated load.
5. Load regulation is measured from 0% to 100% rated load.
6. Length of set up time is measured at cold first start. Turning ON/OFF the power supply very quickly may lead to increase of the set up time.
7. 3.3V,5V when the load factor 0~50%, the switching power less is reduced by burst operation, which will cause ripple and ripple noise to go beyond the specifications.
8. The ambient temperature derating of 5℃/1000m is needed for operating altitude greater than 2000m(6500ft).
9. The power supply is considered a component which will be installed into a final equipment. All the EMC tests are been executed by mounting the unit on a 360mm*360mm metal plate with 1mm of thickness. The final equipment must be re-confirmed that it still meets EMC directives. For guidance on how to perform these EMC tests, please refer to "EMI testing of component power supplies." (as available on http://www.meanwell.com)

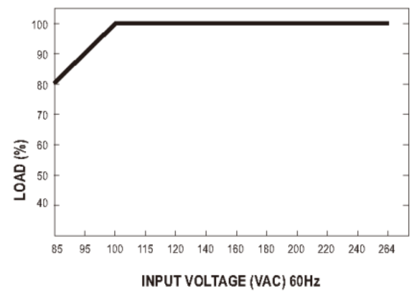
Block Diagram



Derating Curve

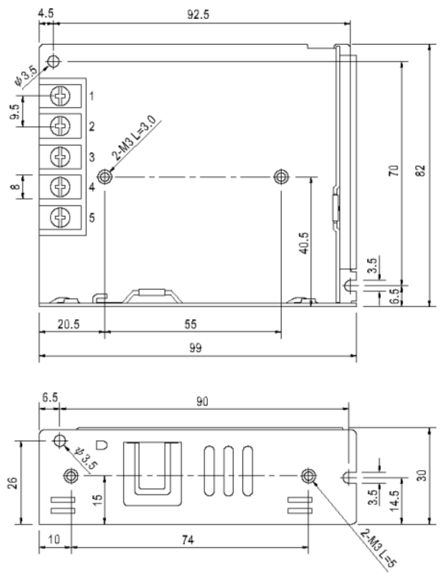


Static Characteristics



Mechanical Specification

Case No.239A Unit:mm



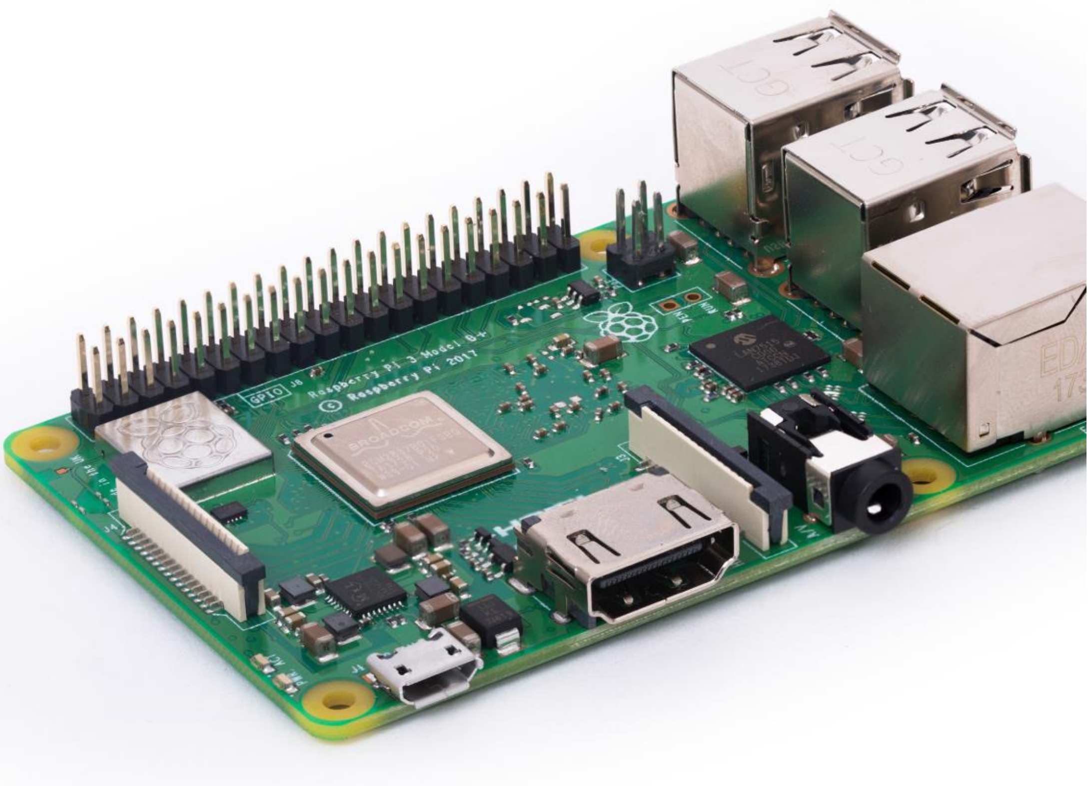
Terminal Pin No. Assignment

Pin No.	Assignment	Pin No.	Assignment
1	AC/L	4	DC OUTPUT -V
2	AC/N	5	DC OUTPUT +V
3	FG ⏚		

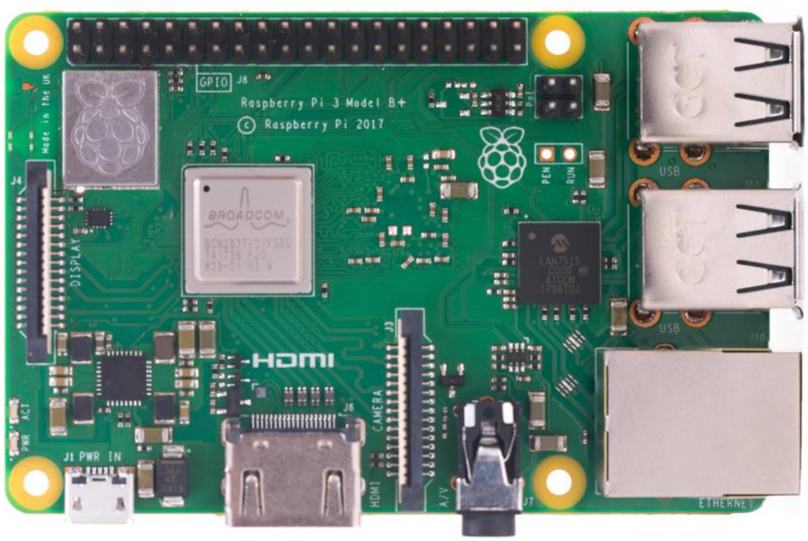
Installation Manual

Please refer to : http://www.meanwell.com/manual.html

Raspberry Pi 3 Model B+



Overview



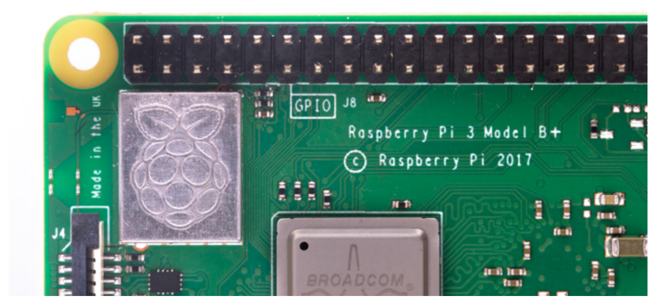
The Raspberry Pi 3 Model B+ is the latest product in the Raspberry Pi 3 range, boasting a 64-bit quad core processor running at 1.4GHz, dual-band 2.4GHz and 5GHz wireless LAN, Bluetooth 4.2/BLE, faster Ethernet, and PoE capability via a separate PoE HAT

The dual-band wireless LAN comes with modular compliance certification, allowing the board to be designed into end products with significantly reduced wireless LAN compliance testing, improving both cost and time to market.

The Raspberry Pi 3 Model B+ maintains the same mechanical footprint as both the Raspberry Pi 2 Model B and the Raspberry Pi 3 Model B.

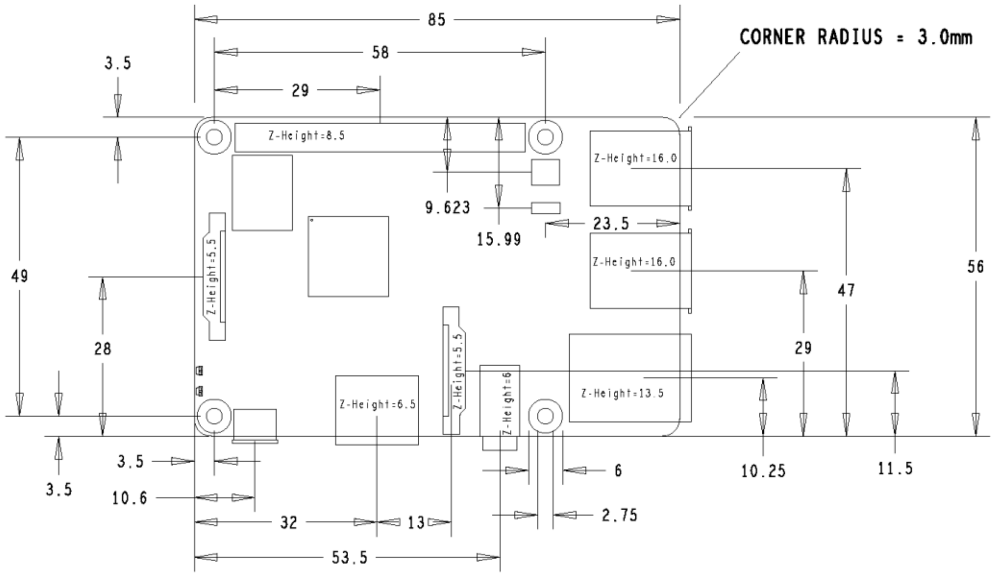
Specifications

Processor:	Broadcom BCM2837B0, Cortex-A53 64-bit SoC @ 1.4GHz
Memory:	1GB LPDDR2 SDRAM
Connectivity:	■ 2.4GHz and 5GHz IEEE 802.11.b/g/n/ac wireless LAN, Bluetooth 4.2, BLE ■ Gigabit Ethernet over USB 2.0 (maximum throughput 300 Mbps) ■ 4 × USB 2.0 ports
Access:	Extended 40-pin GPIO header
Video & sound:	■ 1 × full size HDMI ■ MIPI DSI display port ■ MIPI CSI camera port ■ 4 pole stereo output and composite video port
Multimedia:	H.264, MPEG-4 decode (1080p30); H.264 encode (1080p30); OpenGL ES 1.1, 2.0 graphics
SD card support:	Micro SD format for loading operating system and data storage
Input power:	■ 5V/2.5A DC via micro USB connector ■ 5V DC via GPIO header ■ Power over Ethernet (PoE)–enabled (requires separate PoE HAT)
Environment:	Operating temperature, 0–50°C
Compliance:	For a full list of local and regional product approvals, please visit www.raspberrypi.org/products/raspberry - pi-3-model-b+
Production lifetime:	The Raspberry Pi 3 Model B+ will remain in production until at least January 2023.



raspberrypi.org

Physical specifications



Warnings

- This product should only be connected to an external power supply rated at 5 V/2.5 A DC. Any external power supply used with the Raspberry Pi 3 Model B+ shall comply with relevant regulations and standards applicable in the country of intended use.
- This product should be operated in a well-ventilated environment and, if used inside a case, the case should not be covered.
- Whilst in use, this product should be placed on a stable, flat, non-conductive surface and should not be contacted by conductive items.
- The connection of incompatible devices to the GPIO connection may affect compliance, result in damage to the unit, and invalidate the warranty.
- All peripherals used with this product should comply with relevant standards for the country of use and be marked accordingly to ensure that safety and performance requirements are met. These articles include but are not limited to keyboards, monitors, and mice when used in conjunction with the Raspberry Pi.
- The cables and connectors of all peripherals used with this product must have adequate insulation so that relevant safety requirements are met.

Safety instructions

To avoid malfunction of or damage to this product, please observe the following:

- Do not expose to water or moisture, or place on a conductive surface whilst in operation.
- Do not expose to heat from any source; the Raspberry Pi 3 Model B+ is designed for reliable operation at normal ambient temperatures.
- Take care whilst handling to avoid mechanical or electrical damage to the printed circuit board and connectors.
- Whilst it is powered, avoid handling the printed circuit board, or only handle it by the edges to minimise the risk of electrostatic discharge damage.

Raspberry Pi

APPENDIX E

DOCUMENTATION

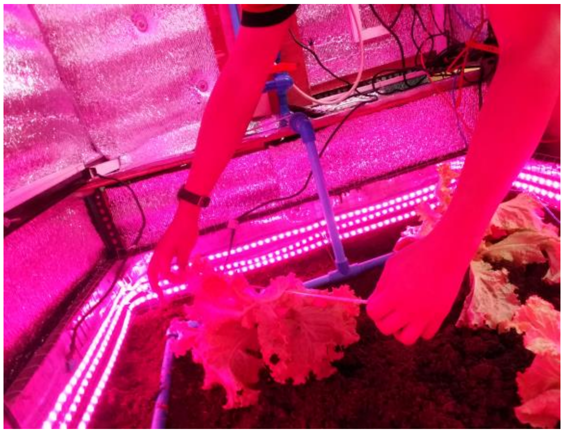
Topic Defense

Progress Defens

Final Defense

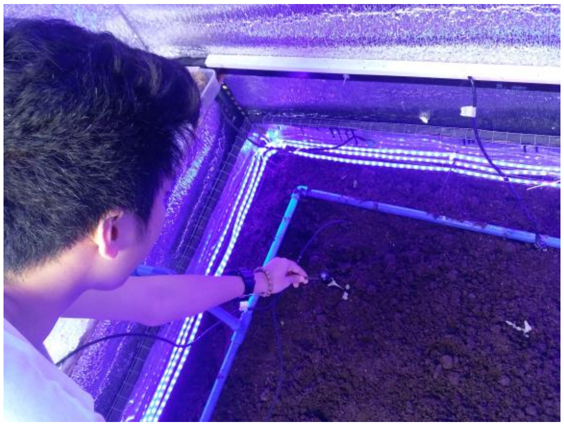
IEEE HNICEM 2019

CROP EVALUATION

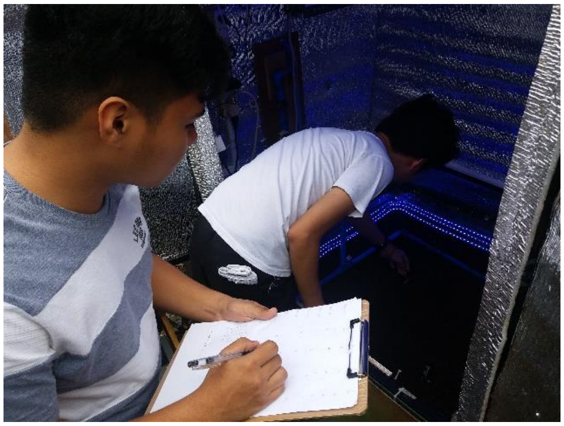


Diameter Measurement

Height Measurement



PAR Measurement



Data Recording

APPENDIX F

CURRICULUM VITAE

Xychryz A-ron P. Calangian

441 Banaba St. Cembo, Makati City
+639206786630
ekswaaay@gmail.com

Education:

Tertiary:
2014 – Present

Bachelor of Science in Electronics and Communications Engineering
Technological University of the Philippines
Ayala Blvd., Ermita, Manila

Thesis and Paper

Thesis : Growth Dependent LED Lighting Control System for Lettuce Through Image Processing Using ANFIS
Co-author | Hardware Designer

Paper : Vision-based Canopy Area Measurements
Co-author | Hardware Designer

Paper : Identification of Lettuce Cultivation Period using Image Processing and Neuro-Fuzzy Inference System *(Publication Pending)*
Co-author | Hardware Designer

Work Experiences:

November 2018 – February 2019

Computing and Archiving Research Environment (Internship)
Department of Science and Technology – Advanced Science and Technology Institute
C.P. Garcia Avenue, Technology Park Complex U.P. Campus, Diliman, Quezon City
Nature of Work
Website Management
Cloud Management
IP Management
Website Installation and Management

Skills:

Specialization

- Image Processing
- Fuzzy Logic
- Adaptive Neuro-Fuzzy Inference System

Basic Programming

- MATLAB
- Octave

Media Editing

- Adobe Photoshop

Design

- Google Sketchup
- AutoDesk Fusion 360
- Multisim
- Express PCB

Computer

- Maintenance
- Troubleshooting
- Software / Hardware installation
- Microsoft Office

Electronics

- Circuit design
- Troubleshooting
- Soldering
- Electrical Wiring

Broadcasting

- Broadcasting Studio and Acoustic Design
- Basic Antenna Design and Fabrication

Affiliations:

- **Institute of Electronics Engineers of the Philippines Manila Student Chapter**
Member (2014 – Present)

- **Organization of Electronics and Communications Engineering Students**
Member (2014 – Present)

Justin Yollo C. Gonzales

47 Principe Tupaz St., Doña Rosario Subd., Novaliches Proper, Quezon City

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j.y.gonzales.07@gmail.com

Education:

Tertiary:

2014 – Present **Bachelor of Science in Electronics and Communications Engineering**
Technological University of the Philippines
Ayala Blvd., Ermita, Manila

Thesis and Paper:

Thesis : Growth Dependent LED Lighting Control System for Lettuce Through Image Processing Using ANFIS
Co-author | Member | Hardware

Paper : Vision-based Canopy Area Measurements *(Publication Pending)*
Co-author | Hardware

Paper : Neuro-Fuzzy Inference System *(Publication Pending)*
Co-author | Hardware

Work Experiences:

November 2018- March 2019 **IT Technical Support (Internship)**

Philippine Postal Corporation
Liwasang Bonifacio, Magallanes Dr, Intramuros, Manila, 1000 Metro Manila
Nature of Work
Installation of computer hardware operating systems and applications
Configuration of computer hardware operating systems and applications
Troubleshooting of computer systems
Diagnosing and solving of hardware or software faults
Replacement of computer parts as required
Testing and evaluation of new technology

Skills:

Electronics

- Circuit Design
- Troubleshooting
- Soldering
- Electrical Wiring

Design

- Multisim
- Express PCB

Computer

- Microsoft Office
- Software/ Hardware Installation

Basic Programming

- Python
- MATLAB
- Octave

Media Editing

- Adobe Photoshop

Affiliations:

- **Institute of Electronics Engineers of the Philippines Manila Student Chapter**
  Member (2016 – 2017)

- **Organization of Electronics and Communications Engineering Students**
  Member (2014 – Present)

Crizel Aile N. Hilario

Blk 61 Lot 22 Jade Street Phase 4 Southfairway Homes
Subdivision Landayan San Pedro , Laguna

+639954645067

crizelaile29@gmail.com

Education:

Tertiary:

2014 – Present	**Bachelor of Science in Electronics and Communications Engineering** Technological University of the Philippines Ayala Blvd., Ermita, Manila

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Thesis and Paper

Thesis : Growth Dependent LED Lighting Control System for Lettuce Through Image Processing Using ANFIS
Co-author | Assistant Leader | Documentation

Paper : Vision-based Canopy Area Measurements
Co-author | Documentation

Paper : Identification of Lettuce Cultivation Period using Image Processing and Neuro-Fuzzy Inference System
Co-author | Documentation

Work Experiences:

November 2018- March 2019	**On-the-job training (Internship)** **National Bureau of Investigation** *United Nations Ave, Ermita, Manila, 1000 Metro Manila* ***Nature of Work*** Sending of message through fax from different agencies inside and outside NBI Sending of message through email from different agencies inside and outside NBI Delivering of message to the different agencies inside NBI Log in of message transmitted and received through fax Log in of message transmitted and received though email Compiling of message transmitted and received Answering inquiries inside and outside NBI

Skills:

Specialization

- Image Processing
- Fuzzy Logic
- Adaptive Neuro-Fuzzy Inference System

Controller Programming

- Arduino
- Raspberry Pi

Basic Programming

- Labview
- MATLAB
- Octave

Media Editing

- Adobe Photoshop
- Concept Draw

Design

- Multisim
- Express PCB

Computer

- Maintenance
- Troubleshooting
- Software / Hardware installation
- Microsoft Office

Electronics

- Circuit design
- Troubleshooting
- Soldering
- Electrical Wiring

Broadcasting

- Basic Antenna Design and Fabrication

Affiliations:

- **Institute of Electronics Engineers of the Philippines Manila Student Chapter**
  Member (2016 – Present)

- **Organization of Electronics and Communications Engineering Students**
  Member (2016 – Present)

John Marcius M. Lopez

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+639420203090

lopezjohnmarcius@yahoo.com | jmbeejoh97@gmail.com

Education:

Tertiary: 2014 – Present	**Bachelor of Science in Electronics and Communications Engineering** Technological University of the Philippines Ayala Blvd., Ermita, Manila

Thesis and Paper:

Thesis: Growth Dependent LED Lighting Control System for Lettuce Through Image Processing Using ANFIS
Co-author | Team Member | Documentation

Paper: Vision-based Canopy Area Measurements
Co-author | Documentation

Paper: Identification of Lettuce Cultivation Period using Image Processing and Neuro-Fuzzy Inference System *(Publication Pending)*
Co-author | Documentation

Work Experiences:

November 2018 – January 2019	**Main Distribution Frame (Internship)** **PLDT Inc. Quiapo** *Pascual Casal St, Quiapo, Manila, 1001 Metro Manila* ***Nature of Work*** Updating the database on telephone numbers of the area Providing connection of dial tones to end users Ensuring a smooth connection of connected dial tones Assisting technicians in repairing bad connections Management of cabling organization

Achievements:

October 2017	*Electronics Technician (ECT)* Licensure Examination passer
April 2018	*PhilNITS IT Passport (IP)* Certification Examination passer

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Skills:

Basic Programming

- MATLAB
- Octave
- Verilog Programming with Xilinx ISE Tool
- Keil uVision
- Proteus

Design

- Multisim

Computer

- Microsoft Office

Media Editing

- Adobe Photoshop

Electronics

- Circuit design
- Troubleshooting
- Soldering
- Electrical Wiring

Others

- Focused, versatile, and multi-task oriented
- Able to adapt effectively to challenging and emergency situation
- Work long hours without physical stress or annoyance

Affiliations:

- **Institute of Electronics Engineers of the Philippines Manila Student Chapter**
  Member (2017 – Present)

- **Institute of Electronics Engineers of the Philippines Manila**
  Member (2017 – Present)

- **Organization of Electronics and Communications Engineering Students**
  Member (2014 – Present)

Boyd Lemuel E. Rulona

1944 Kusang Loob St. Sta. Cruz, Manila 1104

+639667240518

lemuelrulona@yahoo.com

Education:

Tertiary:

2011 – 2014	**Bachelor of Technology in Electronics and Communications Engineering Technology** Technological University of the Philippines Ayala Blvd., Ermita, Manila
2014 – Present	**Bachelor of Science in Electronics and Communications Engineering** Technological University of the Philippines Ayala Blvd., Ermita, Manila

---

Thesis and Paper

Thesis : Growth Dependent LED Lighting Control System for Lettuce Through Image Processing Using ANFIS
Co-author | Leader | Lead Hardware

Paper : Vision-based Canopy Area Measurements
Co-author | Documentation

Paper : Identification of Lettuce Cultivation Period using Image Processing and Neuro-Fuzzy Inference System
Co-author | Documentation

Work Experiences:

November 2013-
August 2014

On-the-job training (Internship)

Fluor Daniel Inc.
Asian Star Bldg. Filinvest, Muntinlupa City

Nature of Work
Telephone Operator
Computer Troubleshoot

April 2018 – May 2018 **On-the-job training (Intership)**

ASERCO
Evangelista St. Pasig City

Nature of Work
Cleaning, Repairing and Checking of Printers
TV Installer

Skills:

Specialization

- Image Processing
- Fuzzy Logic
- Adaptive Neuro-Fuzzy Inference System

Controller Programming

- Arduino
- Raspberry Pi

Basic Programming

- Labview
- MATLAB
- Octave

Media Editing

- Adobe Photoshop
- Concept Draw

Design

- Multisim
- Express PCB

Computer

- Maintenance
- Troubleshooting
- Software / Hardware installation
- Microsoft Office

Electronics

- Circuit design
- Troubleshooting
- Soldering
- Electrical Wiring

Broadcasting

- Basic Antenna Design and Fabrication

Affiliations:

- **Institute of Electronics Engineers of the Philippines Manila Student Chapter**
  Member (2016 – Present)

- **Organization of Electronics and Communications Engineering Students**
  Member (2016 – Present)

Immanuel Jose. C Valencia

16 – 152 Spazio Bernardo, Champaca St., Brgy. Sauyo, Bagbag, Novaliches, Quezon City

+639163877502

immanueljose.valencia@tup.edu.ph | jimcvalencia@gmail.com

Education:

Tertiary:

2016 – Present **Bachelor of Science in Electronics and Communications Engineering**
Technological University of the Philippines
Ayala Blvd., Ermita, Manila

2013 – 2016 **Diploma in Electronics and Communication Engineering Technology**
Technological University of the Philippines
Ayala Blvd., Ermita, Manila

Thesis and Paper

Thesis : Growth Dependent LED Lighting Control System for Lettuce Through Image Processing Using ANFIS
Co-author | Team Leader | Lead Programmer

Paper : Vision-based Canopy Area Measurements
Co-author | Lead Programmer

Paper : Identification of Lettuce Cultivation Period using Image Processing and Neuro-Fuzzy Inference System *(Publication Pending)*
Co-author | Lead Programmer

Work Experiences:

November 2015 – April 2016	**Broadcast Quality Management (Internship)** **ABS-CBN Corporation** *Sgt. Esguerra Ave. corner Mother Ignacia St., Barangay South Triangle, Diliman, Quezon City* ***Nature of Work*** Updating and checking of the departments database Audio and video impairments monitoring Loudness measurement of TV programs Inventory of equipment Assist in technical briefing Research work

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Skills:

Specialization

- Image Processing
- Fuzzy Logic
- Adaptive Neuro-Fuzzy Inference System

Controller Programming

- Arduino
- PIC16F877A
- Raspberry Pi

Basic Programming

- Python
- SQL
- MATLAB
- Octave

Media Editing

- Adobe Photoshop
- Adobe Premiere Pro
- Adobe After Effects
- Final Cut Pro X
- Movavi

Design

- AutoCad
- Google Sketchup
- AutoDesk Fusion 360
- Multisim
- Express PCB

Computer

- Maintenance
- Troubleshooting
- Software / Hardware installation
- Microsoft Office

Electronics

- Circuit design
- Troubleshooting
- Soldering
- Electrical Wiring

Broadcasting

- Basic audio-video level standards
- Basic Antenna Design and Fabrication

Affiliations:

- **Institute of Electronics Engineers of the Philippines Manila Student Chapter**
  Member (2016 – Present)

- **Organization of Electronics and Communications Engineering Students**
  Member (2016 – Present)

- **Radio Amateur Communication Society (R.A.C.S)**
  Member (2013 – 2016)

- **PhySoc (Physics Society)**
  Member (2013 – 2016)