

NeoPixel Sunrise Clock

An intelligent bed lamp



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Key Words: Neopixels, Circadian rhythm, STM, Blue light

Declaration

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3. This report is my own work.
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Date:

Acknowledgments

Abstract

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Chapter 1

Introduction

1.1 Background to the study

The human behavioural and anatomical activities are influenced by several internal cycles. Among them is the **circadian rhythm**, a rhythm studied for many years and whose impacts on the human activity has lead to new interests in the regulation of these activities. Formally defined as a *"cyclical changes in hormones, body temperature, and other biological processes over the course of a 24 hour period"* [1], the **Natural Institute of Health (NIH)** defines it as *"a physical, mental and behavioural changes that follow a roughly 24-hour cycle, reponding primarily to light and darkness in an organism's environment"*[1]. The circadian rhythm plays an important role as its also affect the human sleeping and rising pattern. The circadian rhythm is influenced by the production of *melatonin* produced by the *pineal gland* whose activitties are dependent on the presence of light on the *retinal-hypothalamic tract*[3].These studies have shown that the presence of light with specifics wavelength at certain period of time during a day can affect the normal sleeping cycle.

According to the NIH, there is a correlation between long-term health problems and and sleep disorders [6]. While stress levels and lifestyles affect the sleeping pattern, there is a strong evidence that light have a greater effect. With the invention of the electric light and the recent human exposure to LED screen, human have more exposure to light. Recent researches have shown that the usage of LED technologies at night is linked to sleep deficiency. Blueish light is said to have an huge impact on one of the human internal clock. Sleep deficiency due to inappropriate light exposure can be cured using an optimal light exposure. Researchers were able to quantify, qualify and time the light that is suitable to maintain the natural sleep-awake cycles [2]. With these results, it is possible

to create an environment that will follow user specific light requirement needed to treat patient with sleep disorder.

1.2 Objectives of this study

1.2.1 Problems to be investigated

This project investigates the feasibility of making user friendly embedded system, relatively cheap that could be used as a personal medical device in solving human sleep disorder.

1.2.2 Purpose of the study

The purpose of this study is to create a device that can be used to improve the user's sleeping pattern and to create a user friendly and personalisable digital alarm clock. The product would need to be relatively cheap and have more features than its competitor. Ideally, the NPSC would use medical lighting requirements and patterns for its users in order to be used as a personal medical device in the cure of sleeping disorder.

1.3 Scope and limitations

The scope of this project involves the design of an functional embedded system named **NeoPixels Sunrise Clock** also known as **NPSC**, capable of producing light of $460nm$ with an intensity of $30lux$ as mentioned by the paper "**Action Spectrum for Melatonin Regulation in Humans: Evidence for a Novel Circadian Photoreceptor**". The code and design artefact repository and a full documentation including a user manual, for anybody who wants to make use of the code design resources, also need to be delivered. Moreover, a description of future use of the device in the study of the effect of light on the circadian rhythm will be required.

This project does not study the effect of light on the users. For ethical reasons, the NPSC will not be tested on human subjects in real situations of either waking humans or including lighting to facilitate sleep at night. Instead the system will be tested based on the recommendation from the research literature.

The design and creation of the NPSC is subject to several constraints listed below:

- **Time:** The project has a duration of 12 weeks within which the research, design, development, implementation, verification, and report writing need to be done.
- **Money:** The project budget allocation is **R1000**
- **Light:** The NPSC must be able to produce blue light with wavelength of $460nm$ while providing enough light to meet the requirement of the research paper and provide a various range of colour for sunrise simulation. These requirements narrow the options for choosing the right light emitters.
- **Size:** The NPSC is meant to be a bedside lamp, this implies that it should have a relatively small size to be able to fit on a $50cm * 50cm$ bedside table.

1.4 Plan of development

The project was broken into sections and subsections with an estimated timeline.

The *Gantt Chart* used for this project is shown in fig. 1.1. The project started with the an intensive research on the science related to the human sleeping cycle. The research lead to the design of the NPSC consisting of its hardware and software modules. During the manufacturing process, the software framework of the NPSC was continously improved. The NPSC hardware and software integration were done later after the assembly of the hardware. Finally, the software was improved during the remaining lifetime of the project.

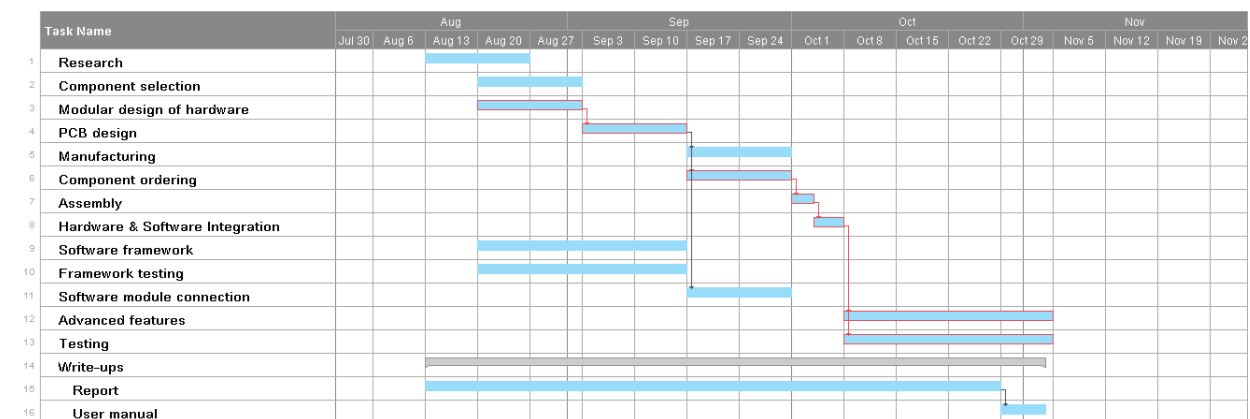


Figure 1.1: Gantt chart showing the timeline of every task in the project as well as its critical path.

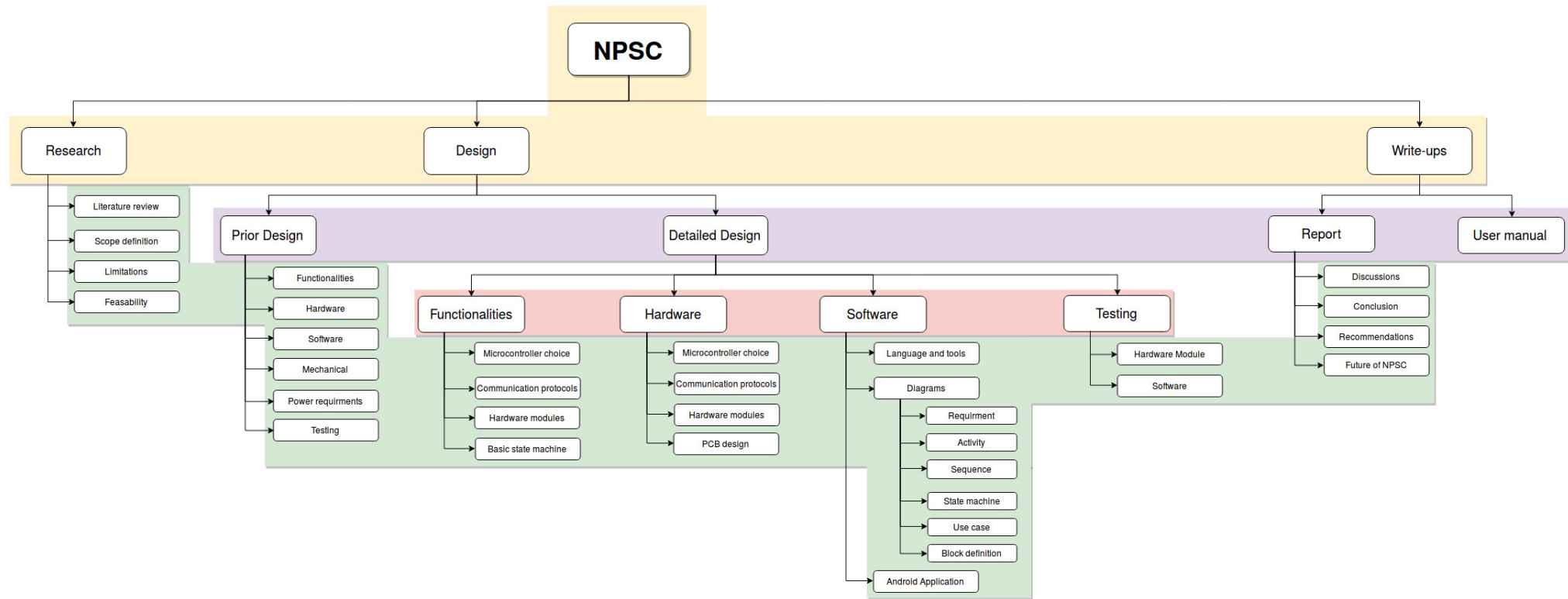


Figure 1.2: Report breakdown detailing the different sections needed to be included in the report.

1.4.1 Chronological progression of the report

The report organisation is displayed in fig. 1.2. The sections of the report are explained below:

- **Research**

- **Introduction:** The feasibility of the project as well as its scope and limitations are defined in the introduction.
- **Literature Review:** The literature review gives an insight in the researches made for this project. This includes scientific discoveries on the human sleeping cycle, experiments and results performed by researchers on that matter, and some technical engineering design decisions.

- **Design**

- **Methodology:** This section covers the hardware, software, and mechanical design of the NPSC.
- **Results:** This section displays the results of the hardware and software testing.

- **Write-ups**

- **Discussion:** The analysis of the results obtained. Here, the performance of the NPSC is evaluated. A costs and functional analysis of NPSC done to evaluate its performance compared to its competitors. Moreover, the future use of the NPSC is elaborated.
- **Conclusion:** An evaluation of the project, did we achieve the intended goals.
- **Recommendations:** We dive into the solutions or recommendations that could improve the design of such device.
- **User manual:** This section is for any users of the NPSC. It provides a clear explanation of the features of the NPSC and a detailed manual.

Chapter 2

Literature Review

This chapter reviews the research papers, articles, books and other relevant form of researches used in the design of the NPSC. It has been divided into the sectioned below:

- The human sleep-wake cycle
- Previous attempts
- Hardware modules and PCB design requirements
- Communication protocols
- Programming Languages
- Software Tools and Libraries

2.1 The human sleep-wake cycle

2.1.1 The circadian rhythm

Many of our seasonal behaviour are synchronised to the environment by **biological clocks** responsible for the creation of circadian rhythms. Biological clocks which are composed of protein that act reciprocally on the body's cells are the natural timing device found in many organs. The discovery of the genes from these biological clocks responsible for the control of the circadian rhythms was made by three scientists Jeffrey

C. Hall, Michael Rosbash and Michael W. Young winners of the Nobel Prize in Physiology or Medicine [14]. Their discovery made in the 1980s led to advanced research on the role of the circadian rhythms.

Circadian rhythms are biological rhythms which follow the same pattern in absence of external cues (endogenous), are influenced by the presence of external stimuli (entertainable), oscillating every 24h over a range of physiological temperatures. In the presence of external stimuli -also known as *zeitgebers*-, circadian rhythms synchronise their periodicity with these external stimuli. The *zeitgebers* of the circadian are the daily variation of the temperature and the dark/light cycle of the day.

Circadian rhythms have an endogenous and an exogenous components. Human placed in isolation without knowledge of the time continued exhibiting a circadian rhythm with their pacemakers notably the melatonin secretion, sleep-wake cycle, body temperature [13]. These results prove the endogenous component of the circadian rhythms. A similar study shows that when people are exposed to light at night time, a shift in their pacemakers [9] which is an evidence of the exogenous component of circadian rhythms. The exogenous components of the circadian rhythms have the ability affect positively and negatively our natural endogenous cycle. With light being what we are mostly daily exposed to, what is the influence of light on the circadian rhythms?

2.1.2 Internal circadian rhythms influenced by light

Melatonin is the hormone produced by the pineal gland in the suprachiasmatic nuclei (SCN) which has a soporific effect and the ability to entertain the sleep-wake cycle. While melatonin itself is not the cause of a person sleeping, it however creates changes in a person's body that affect their sleepiness.

The pineal gland responsible for the secretion of the melatonin hormone is under the influence of one of the biological clocks, the master clock located in the SCN. The SCN receives visual information from the retinal-hypothalamic tract which entrains the SCN according to the photoperiod [3]. The SCN in turn activate a gene in the pineal cell (CREM) which produce a protein (ICER) needed for the production of melatonin. As a result, the secretion of pineal hormone melatonin follow the light/dark cycle with its secretion being high during the day and low during the night.

2.1.3 Quantitative and qualitative characteristics of light on melatonin production

Many researches have been done to understand the impact of light on the circadian rhythms especially the sleep-wake cycle.

Kathleen *et al.* in their paper *Blue light from light-emitting diodes elicits a dose-dependent suppression of melatonin in humans*[4], provide details information on their finding of the effect of light on humans subject. Subjects used for the experiments were 5 males and 3 females with an mean of 23.9 ± 0.5 years, with each subject demonstrating normal color vision. The lighting requirement was blue light of $\lambda_{max} = 469nm \pm 1nm$ with $\frac{1}{2}$ peak bandwidth = $26nm$ and a typical viewing distance of $35cm$. The subjects were blindfolded from midnight to 2AM. From thereon, they were exposed to 90 min of blue light exposure followed by another dark exposure. Blood sample from the subject were taken from 2AM at 30 min interval. From their experiment, they concluded that:

- **Blue LED light has an increased melatonin suppression following an increase in exposure irradiance**
- **Blue LED light may have stronger suppressing effect than 4000K white fluorescent light.**

A similar study was previously made by George C. Brainard *et al.* [5] used 72 healthy human subjects, with normal color vision. The subjects composed of 37 females, 35 males, aged between 18 and 30 years (mean age of 24.5 ± 0.3 years), came from different ethnic (african, african americans, caucasians, asian, hispanic). The melatonin suppression action spectrum was formed using eight different wavelengths between $440nm$ and $600nm$ ($440, 460, 480, 505, 530, 555, 575, 600$). Using the same procedure as mentioned in the previous experiment, blood samples were taken at 30 min interval after 2AM. The results of their research published in their paper *Action Spectrum for Melatonin Regulation in Humans: Evidence for a Novel Circadian Photoreceptor* the following conclusion:

- **Light irradiance greater or equal to $3.1\mu W/cm^2$ evoke a significant melatonin suppression**
- **Smaller wavelength monochromatic light have a greater change in *Plasma Melatonin as Percent Change Control-Adjusted* for a fixed value of *Photon density* ([5] pp. 4-5).**

2.1.4 Impact of light on human behaviour and sleep-wake cycle

Among the Zeitgebers of the circadian rhythms, light being the major Zeitgebers has important effect on the human sleep-wake cycle. Christian *et al.*[2] shown that subjective sleepiness and core body temperature opposes each other ([2], pp. 12, fig. 2.1) when there is no phase lag or lead between the endogenous circadian rhythm and the sleep-wake cycle. The human normal sleep-wake cycle is comprised of 8h of sleep and 16h of wakefulness [15]. This cycle is naturally affected by the human activities but is highly influenced by light exposure. The study shows that office workers with bright blue office light have a better sleep-wake cycle than those with dim and warm office light. Furthermore, it shows that light exposure of sufficient intensity at night can reduce the secretion of melatonin with alerting response starting within the first 20mn. With the recent advance in LED technologies, human are no longer following the natural light/dark cycle causing numerous sleep disorders.

2.2 Lighting technologies

2.2.1 Artificial and natural light

The sun's electromagnetic radiation has a broad light spectrum ranging from $100nm$ to $1mm$. After being filtered through the earth atmosphere, only certain portions of the spectrum are kept with the visible light spectrum having the maximum irradiance. LED technologies are able to produce more or less the same wavelenght as the sunlight but with much less irradiance.

2.2.2 Light treatment of sleep disorder

With the discovery of the effect of light on the sleep-wake cycle, electronic devices producing specific light requirment have been used in treating patient with sleep disorder. Advanced sleep phase disorder (ASPD) have been treated using a therapeutic approach involving chronotherapy and timed light exposure [18]. The same concept has been used to create a home bed lamp or alarm clock facilitating the regualtion of the slepp-wake cycle. **GE Sol** and **Philips**(*which is actively involved in sleep-wake cycle treatement*) have created devices able to “influence” the human sleep-wakr cycle.

C by GE Sol

C shown in fig. 2.1 is a “all-in-one smart light” [16] which has Amazon intelligent personal assistant Alexa built in. *C* has a various range of colours which are manually selected based on the user preference. It is capable of communicating wiht GE sol devices and smartphones inserting it among the user’s network of devices. Despite its high technology features and its elegant design, *C* remains just a bed lamp as it is not clinically proven to be helpful in regulating the user’s sleep-wake cycle.



Figure 2.1: *C* by GE Sol, an intelligent lamp bed using Amazon Alextra.

Philips wake-up lamps

Philips has created a broad range of wake-up lamps designed to impact the sleep-wake cycle of the users. Figures 2.3a and 2.3b are examples of the recent versions of Philips’ clocks able to simulate sunrise and sunset which last from 20 to 40 mn. These simulations vary the colour of the light following the sun’s natural sunrise colour and end with a selected channel or preferred user’s music. These Sleep and Wake-up lights are the only wake-up lamp clinically proven to work as claimed by Philips[17].



(a) HF3531/60, coloured sunrise simulation, 7 natural sounds, Tap snooze and reading lamp, midnight light function



(b) HF3551/60, coloured sunrise simulation, 7 natural sounds, Tap snooze and reading lamp, midnight light function, Operated by iPhone App

Figure 2.2: Wake-up light by Philips

2.3 Hardware modules

2.3.1 Processors and microcontrollers

A microcontroller is a computer, it contains a central processing unit (CPU), it has some random access memory (RAM), it has input and output peripherals. However, a microcontroller is way smaller, cheaper, use less electrical power, and has less processing capabilities than a computer making it the preference for tasks specific electronic design [19].

Numerous microcontrollers were analysed for this project. Each manufacturer provide various range of microcontroller suitable for different application. In order to reduce the complexity of finding the *perfect* microcontroller for the NPSC, the selection was based on the following characteristics:

- **Size of the FLASH:** How many lines of code can be loaded to the microcontroller?
- **Cost**
- **Clock speed**
- **Community:** Does the manufacturer have a large community of developers?
- **Bit precision:** Are we aiming at 8, 16, or 32 bits precision?

- **Familiarity:** How familiar are we with the microcontroller (time is a constraint)?
- **Number of pins:** How familiar are we with the microcontroller (time is a constraint)?
- **Extra features:** What are then built-in functionalities (wifi module, bluetooth)?

Table 2.1 provides the difference between the microcontrollers selected, this table was used in making the final decision of the microcontroller selection.

Characteristics	Microcontrollers			
	Arduino Due	Intel Edison	Raspberry Pi Zero	STM32F407VGT6
Clock speed	84MHz	dual-core, dual-threaded 500 MHz CPU	1GHz single core	168 MHz
Bit precision	32	32	32	32
FLASH	512KB	4GB	MicroSDHC	1MB
Pins	54	40	40	82
Cost	R549.25	R687.87	R79.8	R175.45

Table 2.1: Comparison between specifications of the Arduino Due [20], the Intel Edison [21], the Raspberry Pi Zero [22], and the STM32F407VGT6[23]

2.3.2 LEDs

types of LEDs technology and introduction of the neopixels

2.3.3 Storage

Storages are important in the development of embedded solutions. The **Electrical Erasable Programmable Read-Only Memory** (EEPROM) is a non-volatile memory capable of keeping its data after being powered off. Its design was based on the **Erasable Programmable Read-Only Memory** (EPROM) which required exposure to UV light for erasing its memory. There are two types of EEPROMs, serial and parallel EEPROMs. In a study made by Microship on the difference between serial and parallel EEPROM of 16KB, Tom Tyson from the Memory Product Divisions concluded that the serial EEPROM is *the best option for embedded solutions requiring a small EEPROM footprint, low current and low operating voltage, the ability and ease to programme a byte at a time, and the best price performance non-volatile memory solution available*[24] (pp. 4).

2.3.4 Wireless technology

Different types of wireless technologies allow devices to communicate to each other wirelessly. The Institute of Electrical and Electronics Engineers (IEEE) has grouped them in the 802.15 technologies. Among these are the well known Wifi, the cellular machine to machine (M2M), the mesh network using **ZigBee**, **Z-wave** Bluetooth is the wireless technology of interest in this project. Bluetooth invented in 1994 is an open standard for short range wireless communication. While being low cost, it is subject to limitations namely its short range of operation being around 10m ¹ and its low transmission rate (780kb/s).

2.3.5 Touch screen

A touch-screen device can locate the position of a point of contact on its screen. The idea of using contact pressure of an object in application was initially from Hugh Le Caine with his Electronic Slackbut capable of changing the volume of musical notes based on the amount of pressure applied to the keys. Later in 1969, E. A. Johnson created two major touch-screen technologies using a resistive and a capacitive approach.

A resistive touch-screen is made out of many layers among which two are composed of indium-tin oxide (ITO) which is highly resistive and transparent. By applying pressure on one of the layers, the layers come in contact creating a signal that is used to find the location of the point of contact. A capacitive touch-screen makes use of the conductivity of the object in contact with the screen to affect the electrostatic field between the ITO layers.

Resistive touch-screens are less complex than capacitive touch-screens, thus cheaper. Moreover, because it relies on pressure, any object whether conductive or not can be used on the screen. On the other side, resistive touch-screens do not support multi-touch and have poor contrast because of the extra layer used to protect the ITO layers.

2.4 Communication protocols

Communication protocols

¹Can be increased by increasing the transmission power



(a) Resistive touch-screen technology[28]. (b) Resistive touch-screen technology [29].

Figure 2.3: Touch-screen technologies

2.4.1 Serial Peripheral Interface (SPI) Bus

SPI is a synchronous full duplex serial communication protocol used for short distance communication of electronic devices. With the protocol, one master can communicate to many slaves using a chip select pin (use to select the slave) but a slave can only talk to the master device. SPI uses 4 signals namely, the Master Out Slave In (MOSI), the Master In Slave Out (MISO), the clock (SCK), and the slave select or chip select (SS). Since SPI uses a clock, it does not require the configuration of a baud rate before communication. The main inconvenience with SPI is the number of pin require for a one to one communication, for every additional slave, the master must provide a SS pins which make SPI not the ideal protocol for communicating to multiple slaves devices [30].

2.4.2 Universal asynchronous receiver-transmitter (UART)

UART is a asynchronous full duplex communication protocol making use of two signals a transmit signal (TX) and a receive signal (RX). With UART, both devices need to agree on a baud-rate for communication, this rate define the number of bytes to be sent and received. The problem with UART is the complexity of the protocol required to ensure synchronous communication and correct transfer of information between device. Although theoretically UART baud-rate is infinite, it is practically limited to 230400 bits per seconds [31].

2.4.3 Inter-Integrated Circuit (I2C)

I2C is a serial protocol that allows communications fom multiple slaves to multiple masters. It takes a bit of both SPI and UART by being designed for short distance

communication and requiring only two pins, namely the data line (SDA) and clock line (SCL). Its clock ranges from $100kHz$ to $400kHz$ and a bytes is sent at a time. Furthermore with the I2C protocol, each slave must have a unique address used by the master for communication [32].

2.4.4 Neopixels

Each neopixel has a built-in IC controlling the LEDs' intensity based on the data receive. The neopixels use a single wire communication protocol. When connected in series, the neopixels form a daisy chain allowing the programming of a serie of neopixels using one signal.

Each neopixel requires 24 Bytes (32 Bytes for RGBW LEDs), each bytes is an encoded bit using a Non-Return-to-Zero encoding. Figure 2.4 shows the encoding pulses used.

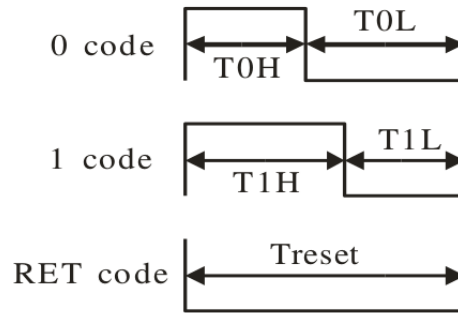


Figure 2.4: Non-return-to-zero encoding of a single bit in the neopixels programming protocol

2.5 PCB Board Design

PCB Board Design advice, best practices

2.6 Programming Languages

2.7 Software Tools and Libraries

Software Tools and Libraries

2.7.1 Toolchain

2.7.2 Nextion

2.7.3 Android Application

A literature review forms the theoretical basis of your project. You need to read a large number of journal papers, sections in books, technical reports etc. relevant to your work at the start of project. This will give you a good idea of the field of research.

When writing your review start of with the general concepts and move to the more specific aspects explaining the necessary theory as you go. This section is NOT a copy and paste from others work or a rewrite-but-change-one-word section. I suggest you read all your material, and then put it down and write this section, referring back to the work only when you need to check something.

See your PCS textbook for more details on how to write a literature review.

Chapter 3

Design

3.1 Design scope and specifications

Scope and Specifications

3.1.1 Scope

3.1.2 Specification

3.1.3 Acceptance test

3.2 Preliminary design

Preliminary design

3.2.1 Modules interaction

3.2.2 Design considerations

Electrical

Communication

Mechanical

Software

3.2.3 Components selection

Microcontroller

Bluetooth

External memory

Sensors

Neopixels

3.3 Emboddiment design

Emboddiment Design

3.3.1 OPM Diagrams

3.4 Hardware Design and Testing

Schematics and hardware testing

3.4.1 Sensors

3.4.2 Neopixel Ring

3.4.3 Neopixel Time and Weekday

3.4.4 Date

3.4.5 EEPROM

3.5 Software Design and Testing

Algorithms and unit tests

3.5.1 Neopixles

3.5.2 Bluetooth

3.5.3 Sensors

3.5.4 RTC

3.5.5 EEPROM

3.6 Setup of Development Environement

Setup of Development Environement

3.6.1 Github

3.6.2 Nextion

3.6.3 Makefile

This is what I did to test and confirm my hypothesis.

You may want to split this chapter into sub chapters depending on your design. I suggest you change the title to something more specific to your project.

This is where you describe your design process in detail, from component/device selection to actual design implementation, to how you tested your system. Remember detail is important in technical writing. Do not just write I used a computer give the computer specifications or the oscilloscopes part number. Describe the system in enough detail so that someone else can replicate your design as well as your testing methodology.

If you use or design code for your system, represent it as flow diagrams in text.

Chapter 4

Implementation and Testing

4.1 Hardware design and testing

Schematics and hardware testing

4.1.1 Sensors

4.1.2 Neopixel Ring

4.1.3 Neopixel Time and Weekday

4.1.4 Date

4.1.5 EEPROM

4.2 Software design and testing

Algorithms and unit tests

4.2.1 Neopixles

4.2.2 Bluetooth

4.2.3 Sensors

4.2.4 RTC

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If you use or design code for your system, represent it as flow diagrams in text.

Chapter 5

Results

These are the results I found from my investigation.

Present your results in a suitable format using tables and graphs where necessary. Remember to refer to them in text and caption them properly.

5.1 Simulation Results

5.2 Experimental Results

Chapter 6

Discussion

Here is what the results mean and how they tie to existing literature...

Discuss the relevance of your results and how they fit into the theoretical work you described in your literature review.

Chapter 7

Conclusions

These are the conclusions from the investigation and how the investigation changes things in this field or contributes to current knowledge...

Draw suitable and intelligent conclusions from your results and subsequent discussion.

Chapter 8

Recommendations

Make sensible recommendations for further work.

Use the IEEE numbered reference style for referencing your work as shown in your thesis guidelines. Please remember that the majority of your referenced work should be from journal articles, technical reports and books not online sources such as Wikipedia.

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Appendix A

Additional Files and Schematics

Add any information here that you would like to have in your project but is not necessary in the main text. Remember to refer to it in the main text. Separate your appendices based on what they are for example. Equation derivations in Appendix A and code in Appendix B etc.

Appendix B

Addenda

B.1 Ethics Forms