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Implementation of Optical Wireless Charging System

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A Project Submitted In Partial Fulfillment for the Requirements of the Degree of B.Sc. (Honor) In Electrical Engineering

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الآية

قال تعالى:

بِسْمِ اللَّهِ الرَّحْمَٰنِ الرَّحِيمِ

" خَلَقَ السَّمَاوَاتِ بِغَيْرِ عَمَدٍ تَرَوْنَهَا وَأَلْقَىٰ فِي الْأَرْضِ رَوَاسِيَ أَنْ تَمِيدَ بِكُمْ وَبَثَّ فِيهَا مِنْ كُلِّ دَابَّةٍ وَأَنْزَلْنَا مِنَ السَّمَاءِ مَاءً فَأَنْبَتْنَا فِيهَا مِنْ كُلِّ زَوْجٍ كَرِيمٍ ﴿١٠﴾ هَٰذَا خَلْقُ اللَّهِ فَأَرُونِي مَاذَا خَلَقَ الَّذِينَ مِنْ دُونِهِ بَلِ الظَّالِمُونَ فِي ضَلَالٍ مُبِينٍ ﴿١١﴾ "

[سورة لقمان 10-11]

DEDICATION

To all whom concerning with technological developments and following the mass movement of scientific apparatus. To our country, people and parents. Our project is such of thousands attempts to prove our innovation and hard working in order to solve our problems and contribute in developing our country.

ACKNOWLEDGEMENT

First and above all, we praise God, the almighty for providing us this opportunity, and granting us the capability to proceed successfully. Project team give sincerely thanks to our supervisor Dr. Awdalla Taifour who helped us with advanced, specific and accurate advanced advices. We also would to thank all who contribute in completing this scientific achievement.

ABSTRACT

Science and technology are continuously developing, especially in the field of wireless power transmission technology, so major tech companies are competing to develop their products to keep pace with this development to provide the best services to their customers. This project aims to design and implement a prototype wireless charger for indoor usage, and 10 cm operational range. The device was relied on the basis of the principle of optical power transmission using infrared technology. The prototype consists of a transmitter, a receiver, a controller, and a load (smart phone), the transmitter sends optical beams through an array of IR LEDs, which received by the photovoltaic cell which is connected to the phone. The importance of the controller is to cut off the rays of the transmitter when intercepted by any object, thus safety concerns were considered. The results showed the possibility of charging the smart phone at a distance of up to 30 cm and the possibility of detecting an object presence within a range of one meter, with a response accuracy of 750 milliseconds, but it was found that the overall efficiency of the system is less than expected due to the low quality of the materials used.

مستخلص

تعتبر تكنولوجيا نقل الطاقة لاسلكيا من المجالات المتطورة باستمرار، لذلك تتنافس شركات التقنيات الكبرى بتطوير منتجاتها لتواكب هذا التطور لتقديم أفضل الخدمات لعملائها. يهدف هذا المشروع إلى تصميم وتنفيذ نموذج أولى لشاحن لاسلكي يستعمل داخليا، وله مدى شحن أكبر من 10 سم. صمم الجهاز على أساس مبدأ نقل الطاقة ضوئيا باستخدام تقنية الأشعة تحت الحمراء. يتكون النموذج الأوليّ من مرسل ومستقبل ومتحكم وحمل (الهاتف الذكى)، يقوم المرسل بإرسال الحزم الضوئية، وتستقبل بواسطة الخلية الكهروضوئية ومنها لشحن الهاتف. تتمثل أهمية المتحكم فى قطع عملية إرسال الأشعة من المرسل عند اعتراضها من أى جسم ؛وذلك لتحقيق نظام السلامة. أظهرت النتائج امكانية شحن الهاتف على بعد يصل إلى 30 سم, و إمكانية تحديد أي جسم في مدى يصل إلى متر بدقة جدة في زمن قدره 750 ملي ثانية, لكن وجد أن كفاءة النظام أقل من المتوقع و ذلك لانخفاض جودة المواد المستعملة .

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CHAPTER ONE

INTRODUCTION

1.1 General Concepts

Recently, science and technology have developed tremendously and incredibly rapid, as it has been possible to find devices with high specifications and performance in a small and portable size. This development affected the existence of various applications that progress on a daily basis, and they are indispensable.

The concept of mobility implies being able to recharge from time to time to use a particular device. The recharging process has multiple methods now available such as: connecting the specific device to its own charger until the battery is full or extracting the battery and connecting it in a custom module and other ways.

Mobile phones, as one of the most important mobile applications in our contemporary world (used by 5 billion in 2017), have developed recharge systems for them, unlike the above-mentioned methods, there are recently developed wireless charging methods by using different techniques such as: inductive coupling, magnetic resonance coupling etc.

1.2 Problem Statement

The aforementioned charging methods face a problem with range as the wire in wired charging constitutes a restriction of the charging process. Although wireless transmission technologies (such as:

inductive coupling, magnetic resonance coupling etc.) have dispensed with wires in mobile phone applications, the problem of range is still present (where the range ranges from several millimeters to several centimeters) and fundamentally affects the efficiency of transmission.

In this project we will try to develop a wireless system with appropriate range and efficiency.

1.3 Objectives

The main objectives of this project are:

- Realizing the concept of convenient wireless charging for mobile phone charging.
- Expand the range to be greater than 10 cm.
- Improve the efficiency corresponding to the mentioned range.

1.4 Methodology

- Determine the appropriate technology among the various technologies in the field of wireless transmission.
- Implementing the selected technology and using it to charge a mobile phone.
- Analyze the results extracted from the experiment.

1.5 Layout

This project consists of five chapters. Chapter one talks about the introduction and gives an overview of the objectives and reasons for the project. Chapter two discusses the literature review and background of the wiring transmission, wireless power transmission, optical power transmission. Chapter three describes the hardware and software considerations of the project. Chapter four illustrates the system implementations and the experimental results. Finally, chapter five shows the conclusion and recommendations.

CHAPTER TWO

THEORETICAL BACKGROUND AND LITERATURE REVIEW

2.1 Energy

Energy is defined qualitatively as the capacity to do work, this definition leads us to the fact that energy is an absolute concept. It may be too complicated to understand and deal with such a concept in practical manners. Hence, this definition encloses the essence of energy into an absolute physical quantity with no realistic practical usage. Therefore another complete and precise definition is provide by Ljubisa R. Radovic "Energy is a property of matter that can be converted into work, heat or radiation." [1].

According to the law of conservation of energy (1st law of thermodynamics) which states that energy can neither be created nor destroyed, we find that the energy of any closed loop system (isolated) is always constant unless it’s added from an outside source [2]. Our planet for example “earth” is a closed loop system - regardless of the energy received from sun and other stars, in this closed loop system energy is constant of course, but it’s represented in various forms delivering from one form to another continuously making a totally balanced system.

2.2 Energy Forms

Energy is generally divided into two categories, potential or kinetic [2]. Potential energy is stored energy and the energy of position, or gravitational energy. On the other hand kinetic energy is the energy of motion [3].

2.2.1 Potential energy types

- **Chemical:** the energy stored in bonds of atoms and molecules which holds these particles together, such as the energy of natural gas and petroleum.
- **Stored mechanical:** energy stored in objects by the application of a force .such as compressed springs.
- **Nuclear energy:** energy stored in nucleus and atom which hold the nucleus together .it can be released when the nuclei are combined or split apart.
- **Gravitational energy:** the energy of position or place.

2.2.2 Kinetic energy types

- **Radiant energy:** electromagnetic energy that travels in transverse waves. It includes visible light and invisible radiations.
- **Thermal energy:** the movement of atoms and molecules within substances, the faster they vibrate and move the hotter the substance becomes.
- **Motion energy:** the energy of the movement of an object from one place to another.
- **Sound energy:** the movement of energy through substances in longitudinal waves.
- **Electrical energy:** the movement of electrons through a wire. This movement per a unit of time is called electrical power.

2.3 Electrical Power

Electrical power has become indispensable for humanity since it was detected first time that is clearly because of the ease of controlling and generating electricity from other energy forms, in addition to its high efficiency despite of the fact that it’s a secondary type of energy [4]. Since the amount of energy of a closed loop systems is fixed as shown earlier, it’s always a matter of energy conversion to have a desired shape of energy or to get any job done, and this is the major concept of generating electricity. Generally, electrical power systems are composed of three main ingredients: power source (transmitter), conveyor medium and a power consumer (receiver).

- **Electrical power sources**

According to the world energy council, these are the electrical power resources in 2016:

- **Solar power**

Depends on the photo electric effect which is the emission of electrons or other free carriers when electromagnetic radiation hits material. Solar power has been developing continuously reaching around 227GW at the end of 2015, which is about 1% of all electricity used globally. Solar cost has also become cheaper (from ~ US$4/W in 2007 to ~ US$1.8/W in 2015) [5].

- **Marine**

The movement of waves in oceans and seas creates a vast store of energy which is used to rotate turbines generating electricity.0.5 GW of commercial marine energy generation capacity is in operation and another 1.7 GW under construction, with 99% of this accounted for by tidal range. The total theoretical wave energy potential is 32 PWh/y, but is heterogeneous and geographically distributed, technology costs for marine energy are still very high, hindering deployment [5].

- **Uranium and nuclear power**

Nuclear reactions are used to make heat and then steam which rotates turbines. Global uranium production increased by 40% between 2004 and 2013, at the end 2015 65 nuclear reactors were under construction with a total capacity of 64 GW [5].

- **Waste-to-energy**

Waste-to-Energy (WtE) occupies less than 6% of the total waste management market, the global WtE market was valued at approximately US$25 billion in 2015.

- **Hydropower**

Hydropower is the leading renewable source for electricity generation globally, the global hydropower capacity increased by more than 30% between 2007 and 2015 accounting to a total of 1209 GW in 2015 [5].

- **Wind**

Global wind power generation reached 432 GW in 2015, about 7% of total global power generation capacity [5].

- **Coal**

Coal is available in most parts of the world, it's also the cheapest fossil fuel [6], but its harm environmental effects made Coal production decreased with 0.6% in 2014 and with a further 2.8% in 2015. Coal still provides around 40% of the world's electricity [5].

- **Geothermal**

Geothermal global output is estimated to be 75 TWh for heat and 75 TWh for power [5].

- **Bioenergy**

Bioenergy is the largest renewable energy source with 14% out of 18% renewables in the energy mix and supplies 10% of global energy supply [5].

Generated electricity is delivered to the consumer using wires, these wires are implemented to an electrical system according to its own characteristics (transmitted, voltage, current, length, temperature ...etc.).

2.4 Electrical Power Transmission

Electrical power can be transmitted through different distances, two main techniques are used in the field, wired power transmission and wireless power transmission.

2.4.1 Wired power transmission

In such power transmission systems, wires are used as conveyer medium which transport electrical power between sources and receiver. The percentage of the power loss during transmission and distribution is approximately 26% because of wires resistance [7]. Besides that, these wires are not always feasible to reach receiver's location, the may restrict applications where a moving receiver is applied. And that's why wireless power transmission concept is developed.

2.4.2 Wireless power transmission

Wireless power transmission is the technology that enables a power source to transmit electromagnetic energy to an electrical load across an air gap, without interconnecting cords [8]. Recently, this technology has been growing up quickly and many applications based on it has appeared such as charging smart phones and tablets, electric vehicles, medical devices , Led lighting…… etc.

The utilization and evolving of wireless power transmission from theories heading to standards features on commercially products especially in the field of wireless charging have many reasons such as: keeping devices charged without needing to actively manage the battery. Providing a suitable method to charge and power billions of electrical devices at different locations [9]. Eliminating battery replacement and eliminating the use of physical connectors and cables. Table 2.1 shows a comparison between wired and wireless system:

Table 2.1: Comparison between wired and wireless systems

Efficiency Parameter	**Wired System**	**Wireless System**
Performance	High	High
Time	Less	Less
Cost	High	Low
Losses	Moderate	Average
Sensitivity	Moderate to less	High
Reliability	Moderate to less	High

The principle of wireless power transmission was discovered in 1894 by "Nikola Tesla" who wanted to transfer electrical energy wirelessly over long distances using big coupled electromagnetic resonators, he could light up phosphorescent and incandescent lamps. He patented on a device called the high-voltage "Tesla coil". Also Tesla could light up 200 bulbs and run an electric motor over 25miles [10]. In 1920s and 1930s magnetrons were invented to convert electricity into microwaves, which enabled wireless power transfer over long distance but there was no method to convert microwaves back to electricity. In 1963 W.C. Brown showed the first microwave wireless power transmission system. Also at the same decade specifically in 1968 the concept of solar power satellite was introduced for wireless power transfer and resonant inductive coupling was applied in implantable medical devices [8]. In California 1975 Wireless high-power transmission using microwaves experiments in the tens of kilowatts have been performed at Goldstone. In 1993 from the University of Auckland in New

Zealand, Professor John Boys and Professor Grant Covic developed systems to transfer large amounts of energy across small air gaps [10].

Wireless power transmission can be classified according to three considerations: technology, application and transmission type. Figure 2.1 shows the classifications of wireless power transmission.

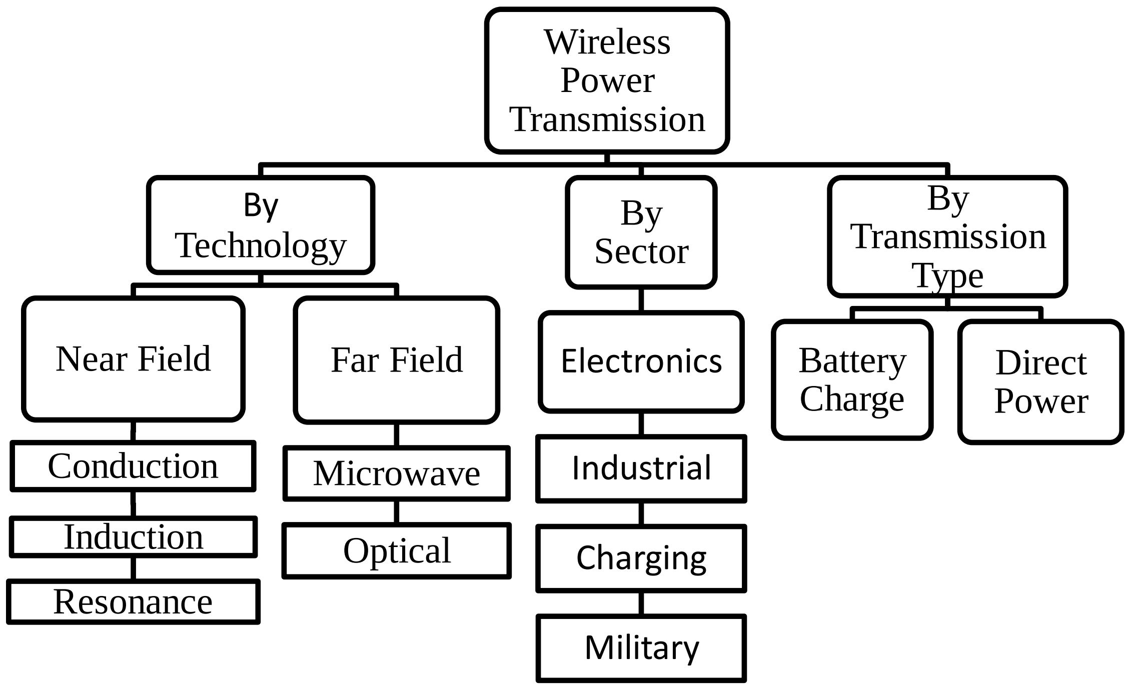

Figure 2.1: Classification of wireless power transmission

2.5 Wireless Charging Techniques

There are different various technologies used to transmit electrical power wirelessly, they varies in efficiency, range, safety, and components required for the implementation.

2.5.1 Inductive coupling

Inductive coupling is kind of near-field techniques which the power loss is extremely proportional to distance. Inductive coupling generally defined as coupling between to LC circuits where resonant frequency is same. It works by using magnetic field induction that is the natural part of current's movement through wire [12]. Inductive power transfer (IPT) happens when a primary coil of an energy transmitter generates predominantly varying magnetic field across the secondary coil of the energy receiver within the field, generally less than a wavelength [8]. Inductive coupling has been an important and popular technology to transfer power without wires with this technological application various kinds of electronic devices has been already made. Therefore, it has been successfully commercialized to a number of products, including electric toothbrush, charging pad for cell phone or laptop, and medical implants [12] the wireless power transmission using inductive coupling has relationship with the distance range of the used frequency and the results show that the shorter the distance, the higher is the voltage transferred. Shielding materials like the presence of books, hands and certain types of plastics do not affect the wireless power transmission much [13]. Despite of the advantages of inductive coupling like low maintenance, durability, less wear and tear on the socket of the device there are disadvantages such as efficiency is lower, charging is slower and doesn't work over large distance. Figure 2.2 shows inductive coupling.

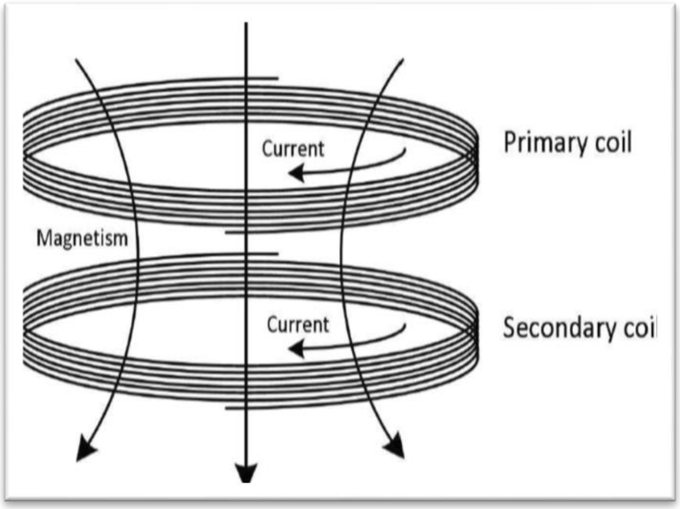

Figure 2.2: Inductive coupling

2.5.2 Capacitive coupling

Capacitive coupling is known as electric field coupling or electrostatic coupling. It is a coupling method generated due to the existence of distributed capacitance. Capacitive coupling transmits the signal from the first stage to the second level through the electric field [14]. Capacitive coupling electrode has many applications. Most of the applications are interacting between the human body and the machine such as Capacitive touch screen, Fingerprint identification, Electrocardiogram signal acquisition and a pressure sensing device for measuring device [14].

2.5.3 Magnetic resonance coupling

This technology was developed by Kurs et al. It enables making the interactions between two different objects very strongly because of the combination of inductive coupling and resonance [12]. It is based on evanescent wave coupling which generates and transfers electrical energy between two resonant coils through varying or oscillating magnetic fields. As two resonant coils operating at the same resonant frequency are strongly coupled, high energy transfer efficiency can be achieved with small leakage to non-resonant externalities [8].

In this technology, energy can be transferred efficiently from a source coil to a receiver coil with little loss of energy. The alternating current in a primary coil (connected to a source) generates a varying magnetic field that induces a voltage across the terminals of a secondary coil at the receiver [12].

2.5.4 Microwave/radio waves

Microwave is a radio wave. It has a wavelength range of 1 mm to 1 meter and frequency range from 3000 MHZ to300 GHZ. Microwaves have wavelength that can be measured in centimeters. Microwaves are good for transmitting information from one place to another because microwave energy can penetrate haze, light rain, snow, clouds and smoke [15]. This technology transfers high power from the base station to the receiving station or mobile devices with two places being in line of sight [12]. It has some disadvantages such as: drastic effects to human body because of its radiation, it also has costly practical possibilities.

2.6 Optical Wireless Power Transmission

Depending on the fact that light as a form of energy can be radiated from several known energy forms and the vice-versa, researchers a long history got attracted in how to quarry, exploit and orient the most of light characteristics to be practically used in technological and even non-technological aspects. For instance the field of information technology and their use of fiber-optic networks in order to have extremely high speed which equals speed of light, reliable and the most accurate communication technique [16]. Based on light nature, optical power can be represented and described by its abstract optical parameters or the parameters related to the sphere and the radiated power.

Generally, in far-field wireless power transmission power beaming is used, power is transferred by beams of electromagnetic radiation. One of the ways to obtain electromagnetic radiation is using High Power Infrared Light Emitting Diodes (IR LEDS), based on the electroluminescent phenomenon, which is defined as the direct conversion of electrical power into radiation [17] . It's very important to differentiate between the electroluminescence and the incandescence (thermal radiation) which is the visible electric radiation emitted by a material heated to high temperature over 650 c [17]. The transmitter then converses electricity into an invisible radiation at the normal temperature of the room.

This technique can transport energy to longer distances but the beamed light must be aimed at the receiver. When the application is transmitting electrical power optically either through coherent tight beam of light or diffused radiated light, parameters take our attention are:

- **Optical intensity**

In case of non-divergent tight power beam (radiated as laser beam) intensity of light is the amount of light power in watts per area. And the amount of power in watts per steradian in case of divergent light (radiated with relatively big beam angle). Optical light intensity is the closest parameter to safety concerns and it’s expressed as Maximum Possible Exposure (MPE) [18].

A tight beam of high power infrared light is considered unsafe to the living cells. Its effect includes the outer skin and the retina, causing a total blindness or a painful sores. The type of damage inflicted depends on the wavelength, pulse energy, pulse width, power, and repetition rate. Eye and skin damage may be immediately painful, or not noticed for a time [19].

Safety limits are primarily varied by wavelength and duration of exposure. Generally, the longer the wavelength and the shorter the duration of exposure, the safer the system for operation. The Maximum Permitted Exposure (MPEs) is the amount of radiation per unit area (power density or intensity), (Optical Power (w) / Area (m^2)) that humans can safely be exposed to [20]. The table 2.2 shows biological hazards that are considered with the standard IEC/EN 62471.

Table 2.2: Biological hazards that are considered within different wavelength ranges in accordance with the standard IEC/EN 62471.

Hazard	Wavelength Range(nm)	Eye effect
1.Actinic UV skin and eye	200-400 (weighted)	Cornea: photo keratitis Conjunctiva: conjunctivitis Lens: cataractogenesis
2.UVA eye	315-400	Lens: cataractogenesis
3.Retinal blue light	300-700 (weighted)	Retina: photo retinitis
4.Reginal blue light small source	300-700 (weighted)	Retina: photo retinitis
5.Retinal thermal	380-1400 (weighted)	Retina: retinal burn
6.Retinal thermal weak visual Stimulus	780-1400 (weighted)	Retina: retinal burn
7.Infrared radiation	780-3000	Cornea: corneal burn Lens: cataractogenesis
8.Thermal skin	380-3000	———

Therefor the need of a safety system must be considered. A system that monitors the operation medium and also capable of making actions within acceptable amount of time.

- **The wavelength of the light**

Wavelength is related to visibility and safety of the radiation. Visibility implies two spectrums of electromagnetic radiation, the visible spectrum is the portion of the electromagnetic spectrum which is visible to the human eye. Electromagnetic radiation in this range of wavelengths is called visible light or simply light. A typical human eye will respond to wavelengths from about 380 to 740 nanometers [22]. This visible spectrum is concerned by solar cells, which are designed to harvest optical power transmitted from the sun or optical power transmitted artificially but at the visible spectrum.

On the other hand, the non-visible optical power types are restricted to: Gamma ray, X-ray, Ultraviolet, Infrared (IR), microwave and Radio. The Table 2.3 demonstrates the relationship of each type to the electromagnetic spectrum:

Table 2.3: Electromagnetic spectrum

Name	Wavelength
Gamma Ray	Less than 0.01 nm
X-Ray	0.01 nm – 10 nm
Ultraviolet	10 nm – 400 nm
Visible	400 nm – 700 nm
Infrared	700 nm – 1 mm
Microwave	1 mm – 1 m
Radio	1 m – 100,000 km

The transmission of power wirelessly using optical electromagnetic waves is not new. In 1895, J. C. Bose demonstrated milli-meter waves by using power transmission to explode gun-powder at a distance [20].

Reviewing what scientists reached so far on the technology of electrical power transmission based on light, laser power beaming isn't a new concept. A startup company called Wi-Charge has introduced an approach based on infrared tight beam of laser. Since the idea of laser can be described as a device that bounces light between a pair of mirrors on either end of a gain medium, which amplifies the light with each successive pass. Usually one of the mirrors inside this cavity is partially transparent allowing some of the light to exit as a laser beam. Wi-Charge's ingenious idea was to take this cavity [23]. And they made the receiver plays a retro reflective role in addition to be high efficient photovoltaic cell. Wi-charge laser based beam is classified a class 1 light beam radiation which is red laser (safe under all conditions of normal use) and more importantly the "external cavity" design means that the instant of anything crosses the path of the laser—your hand, your eye—amplification will stop and the energy will drop [24].

One of the big advantages of Wi-Charge's technology is its ability to deliver almost any amount of power, from few milli-watts for sensor powering to hundreds of watts used in industrial or even military applications. For the consumer market with devices such as smart phones and wearables, Wi-Charge is looking to start with a system capable of delivering 10 W.

Another approach was introduced by IEEE member Aakash Sahai at the International Conference on Space Optical Systems and Applications. He studied and ran a preliminary experiments on an Optical Wireless Power Transmission system that operates at long wavelengths. Hence Optical fields at long wavelengths > 1400nm have lower absorption losses and have higher threshold power density for human safety [20].

He started from the point that safety varies with wavelength according to the standard provided by IEC 60825-1 [25], which limits the human exposure for the laser light. So the longer the wavelength the safer it's in general. Because of the long wavelength e.g.: 1410nm a Gallium Antimonide (GaSb) diode had been used instead of Silicon based photovoltaic cells. The Table 2.4 shows the Sahai's experimental results.

Table 2.4: Aakash Sahai experiment

Voc	6.67	V
Isc	0.315	A
V max	3.93	V
I max	0.15	A
P max	0.59	W

He was able to deliver 0.59 w which could charge a 5v cell phone in approximate 17Hrs, battery capacity considered as 2000 mAH.

Moving to the University OF Washington, USA we found a novel laser-based wireless power delivery system. Their application was to charge a smartphone wirelessly cross a room. They also introduced a Detection of motion approaching the beam, so safety concerns were satisfied [26]. They delivered more than 1 W of electrical power at a range up to 3.66 m using single cell from MH GoPower company which is a Si based PV cell with ~20% efficiency.

The Table 2.5 demonstrates the comparison between different wireless power transmission technologies.

Table 2.5: Wireless power transmission technologies

Technology	Energy Transfer	Enabling Power Transfer
Inductive coupling	Magnetic fields	Coils of wire
Resonant coupling	Magnetic fields	Resonant circuits
Capacitive coupling	Electric fields	Conductive coupling plates
Magneto-dynamic coupling	Magnetic fields	Rotating permanent magnets
Microwave radiation	Microwaves	Phased arrays/dishes
Optical radiation	Light/infrared/ultraviolet	Lasers/photocells

CHAPTER THREE

HARDWARE AND SOFTWARE CONSIDERATIONS

3.1 System Description

The system consists of a power supply which converts the power input (220V AC, 50 Hz) into the suitable system’s power (12V, 1A), then the transmitter (IR LEDs array) converts electricity into an invisible radiation at the normal temperature of the room, then the receiver (solar cell) receives the rays from the IR LEDs and transfers it into electricity. The output of the solar is connected to the load (mobile phone). The function of the controller (ARDUINO MEGA, NANO) is to cut off the rays when any obstacles (human, ...etc) cuts the space between the transmitter and receiver to realize the safety system. Figure 3.1 shows system block diagram.

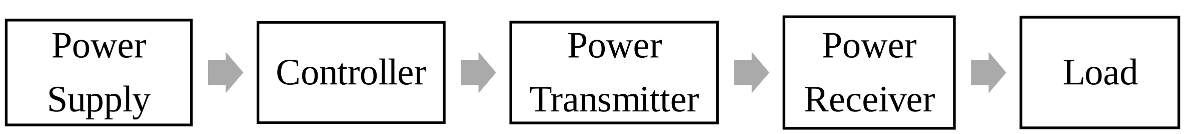

Figure 3.1: Block diagram

3.2 System Hardware

The system main objectives require specific components to implement the electrical power transmitter, the optical power conversion, and the safety system. These components are:

- **AC-DC converter (adapter)**

An AC-DC adapter is a type of external power supply is used with electrical devices that require power but do not contain internal components to derive the required voltage and power from mains power. The advantages include safety, heat reduction, weight and size, and configuration versatility. Adapter’s basic characteristics as shown in Table 3.1.

Table 3.1: Adapter’s basic characteristics

Adapter Model	ADS-187FP-12 120 18GPB
Technicolor P/N	3733786A
Input voltage	100 – 240 AC
Frequency	50/60 Hz
Maximum input current	0.6 A
Output voltage	12 V
Maximum output current	1.5 A

- **5 mm round type IR LED**

IR LEDs performs the transmitter’s section role, which is transforming electrical power into radiation depending on the electroluminescent phenomenon as mentioned earlier.

The LIR053 as shown in Figure 3.2 is high intensity gallium arsenide infrared emitting diodes encapsulated in blue transparent or water clear plastic package. The Table 3.2 demonstrates the electro optical characteristics.

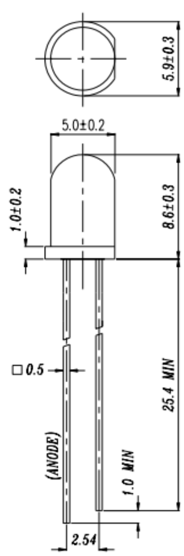

Figure 3.2: IR LED’s dimensions in millimeters

Table 3.2: Electro-optical characteristics (Ta=25℃)

Parameter	Symbol	Condition	Min.	Typ.	Max.	Units
IF=20mA	7.8	15	--	Radiant Intensity	Ee	mW/sr
IF=100mA Pulse Width≦ 100μ s ,Duty≦ 1%	--	60	--			
IF=1A Pulse Width≦ 100μ s ,Duty≦ 1%	--	450	--			
Peak Wavelength	λ p	IF=20mA	--	940	--	nm
Spectral Bandwidth	Δλ	IF=20mA	--	45	--	nm
IF=20mA	1.2	1.5	Forward Voltage	VF	V	
IF=100mA Pulse Width≦ 100μ s ,Duty≦ 1%	--	1.4	1.85			
Reverse Current	IR	VR=5V	--	--	10	μ A
View Angle	2θ ½	IF=20mA	--	20	--	deg

- **Photovoltaic cell**

Photovoltaic cell performs the receiver section's role, which is transforming back the radiant power into electric power based on the concept of charge separation at an interface of two materials of different mechanism, normally between solid-state materials, either n- and p-type regions with electron and hole majority carriers in a semiconductor-metal junctions. UXCELL 80*80 mm solar cell as shown in Figure 3.3 is used in our project with the specifications shown in Table 3.3.

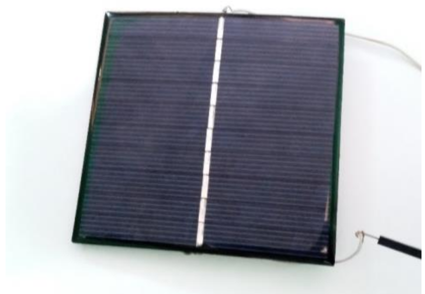

Figure 3.3: UXCELL 80*80 mm photovoltaic cell

Table 3.3: Photovoltaic cell characteristics

Voltage	5v
Dimension	80*80mm (L*W)
Power	0.8W
Brand	UXCELL
Material	Polycrystalline
Net Weight	26g
Main color	Black

- **Lithium-ion battery**

A battery is a device that converts chemical energy into electrical energy and vice versa. Li-ion battery chemistries have the highest energy density and are considered safe. No memory or scheduled cycling is required to prolong battery life. Li-Ion batteries are used in electronic devices such as cameras, calculators, laptop computers, and mobile phones, and are increasingly being used for electric mobility. Their advantages are High specific energy and high load capabilities with power cells, High capacity, low internal resistance, good efficiency and Simple charge algorithm and reasonably short charge times. Table 3.4 shows battery's characteristics.

Table 3.4: Battery's basic characteristics

Nominal Voltage	3.8 V
Watt Hour	5.70 Wh
Charge Voltage	4.35 V
Ampere Hour	1500 mAh

- **ARDUINO**

ARDUINO is an open-source electronics platform based on easy-to-use hardware and software Company, project, and user community that designs and manufactures single-board microcontrollers and microcontroller kits for building digital devices and interactive objects that can sense and control objects in the physical world. The controller of the system consists of two kinds of ARDUINO:

I. ARDUINO MEGA 2560

The ARDUINO MEGA 2560 is a microcontroller board based on the ATMEGA2560. The MEGA 2560 is an update to the ARDUINO MEGA, which it replaces.

It has 54 digital input/output pins (of which 14 can be used as PWM outputs), 16 analog inputs, 4 UARTs (hardware serial ports), a 16 MHz crystal oscillator, a USB connection, a power jack, an ICSP header, and a reset button. It contains everything needed to support the microcontroller.

The ARDUINO MEGA2560 as shown in Figure 3.4 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 Ground (GND) and (Vin) pin headers of the power connector.

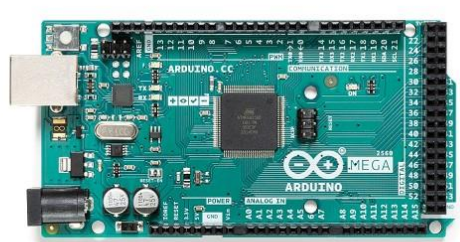

Figure 3.4: ARDUINO MEGA 2560

The power pins are as follows:

- Vin: The input voltage to the ARDUINO board when it's using an external power source. We can supply voltage through this pin.
- 5v: It used to power the microcontroller and other components on the board.
- 3.3v: A 3.3 volt supply generated by the on-board regulator. Maximum current draw is 50 mA.
- GND: Ground pin.

Each of the 54 digital pins on the MEGA can be used as an input or output, using pin Mode, digital Write, and digital Read 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 kilo ohms. One of these pins is Pulse Width Modulation (PWM), 0 to 13 pins Provide 8-bit PWM output with the analog Write function.

Also 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 analog Reference function.

The ARDUINO MEGA2560 can be programmed with the ARDUINO software. It comes pre burned with a boot loader that allows you to upload new code to it without the use of an external hardware programmer. It communicates using the original STK500 protocol. Table 3.5 shows the specification of the ARDUINO MEGA 2560.

Table 3.5: Specification of the ARDUINO MEGA2560

Microcontroller	ATMEGA2560
Operating Voltage	5V
Input Voltage (recommended)	7-12V
Input Voltage (limit)	6-20V
Digital I/O Pins	54 (of which 15 provide PWM output)
Analog Input Pins	16
DC Current per I/O Pin	20 mA
DC Current for 3.3V Pin	50 mA
Flash Memory	256 KB of which 8 KB used by boot loader
SRAM	8 KB
EEPROM	4 KB
Clock Speed	16 MHz
LED_BUILTIN	13
Length	101.52 mm
Width	53.3 mm
Weight	37

II. ARDUINO NANO

ARDUINO NANO is a small, complete, and breadboard-friendly board based on the ATMEGA328 (ARDUINO NANO 3.x) as shown in Figure 3.5. It comes with exactly the same functionality as in ARDUINO UNO but quite in small size.

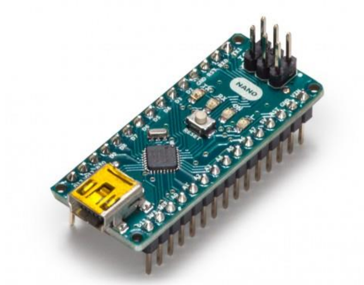

Figure 3.5: ARDUINO NANO

ARDUINO NANO Pin out contains 14 digital pins, 8 analog Pins, 2 Reset Pins & 6 Power Pins. Each of these Digital & Analog Pins are assigned with multiple functions but their main function is to be configured as input or output. These are three methods to power the ARDUINO NANO:

- USB Jack: Connect the mini USB jack to a phone charger or computer through a cable and it will draw power required for the board to function.
- Vin Pin: The Vin pin can be supplied with a unregulated 6-12V to power the board. The on-board voltage regulator regulates it to +5V.
- +5V Pin: If you have a regulated +5V supply then you can directly provide this o the +5V pin of the ARDUINO.

- The digital pins can be used to interface sensors by using them as input pins or drive loads by using them as output pins. A simple function like pin Mode and digital Write can be used to control their operation. The operating voltage is 0V and 5V for digital pins. The analog pins can measure analog voltage from 0V to 5V using any of the 8 Analog pins using a simple function liken analog Read. These pins can be used for special purposes, one of them is PWM, PWM Pins 3, 5, 6, 9 and 11: These pins provide an 8-bit PWM output by using analog Write function. Table 3.6 shows the specification of ARDUINO NANO.

Table 3.6: ARDUINO NANO's specification

Microcontroller	ATMEGA328
Architecture	AVR
Operating Voltage	5 V
Flash Memory	32 KB of which 2 KB used by boot loader
SRAM	2 KB
Clock Speed	16 MHz
Analog IN Pins	8
EEPROM	1 KB
DC Current per I/O Pins	40 mA (I/O Pins)
Input Voltage	7-12 V
Digital I/O Pins	22 (6 of which are PWM)
PWM Output	6
Power Consumption	19 mA
PCB Size	18 x 45 mm
Weight	7 g

- **Single channel relay**

Relays are electrically actuated switches that use a solenoid to make or break the mechanical contact between electrical leads. They are electrically operated device that has an input circuit and an output circuit. It's frequently used in automatic control circuits to control high-current path with low-current signal [27].

The operation of the relay is based on electromagnetic induction. When a current passes through its coil, it magnetizes the coil, therefore creating an electromagnetic field that has specific magnetic polarity. This magnetic field once initiated, it will attract the metallic armature, and as a response to the attraction, a contacting points will be attached together or detached from each other.

The input circuit of the relay (the induction part) represents an input variable like current, voltage, power, resistance, frequency etc. And when the rated value of input (voltage, current and temperature etc.) is above the critical value, the controlled output circuit of relay will be energized or de-energized.

Typical 1-channel 5 v relay specifications:

- 1-channel high voltage system output, meeting the needs of single channel control.
- Contact current 10A and 250V AC or 30V DC.
- With size: 43 x17x18. 5 mm, Net weight: 15 g.
- Able to control high load current, which can reach 240V, 10A AC or DC.
- Has single pair of Normally-Open (NO) and Normally-Close (NC) contacts.

The output contacts of a relay (including NO, NC, and the common port). Its operating principle is as follow: VCC----5V, GND----for ground, IN1 connects to the control valve which output 3V-5V, Output contacts: connect to applications.

The relay is designed to interface with microcontroller such as ARDUINO, PIC and etc. And it comes with a LED to indicate the status of relay.

- **TSOP 1838 IR receiver**

Receiving IR codes requires a special infrared sensor, which demodulates the received signal and splitting up the carrier signal from the information signal. For such a process TSOP 18xx series meet our operation requirement (i.e. to receive IR rays from an IR LED and demodulate it, then use the decoded code along with controller to implement our safety algorithm).

The TSOP18xx series are miniaturized receivers for infrared remote-control systems. PIN diode and preamplifier are assembled on lead frame, the epoxy package is designed as IR filter. The demodulated output signal can directly be decoded by a microprocessor. The main benefit is the reliable function even in disturbed ambient and the protection against uncontrolled output pulses.

Typical TSOP 1838 IR sensor showed in Figure 3.6 has the following specifications:

- Photo detector and preamplifier in one package.
- Internal filter for PCM frequency.
- TTL and CMOS compatibility.
- Output active low.
- Improved shielding against electrical field disturbance.
- Suitable burst length ≥6 cycles/burst.

- Small size package.
- Enhanced immunity against all kinds of disturbance light.
- No occurrence of disturbance pulses at the output.
- Short settling time after power on (<200s).
- Operates with 38 kHz carrier frequency.

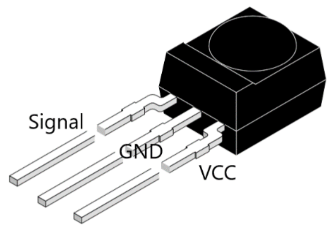

Figure 3.6: TSOP 1838 IR receiver

3.3 System Software

In order to deal with IR remote control systems with ARDUINO we use the multi-protocol infrared remote library “IR Remote”. The library was written and is maintained by Ken Shirriff. It let us send and receive IR remote codes in multiple protocols [29, 30].

Both the HEX code and Manufacturers code must be specified when using the library. Once they are determined, we will need another bit of information – the number of bits to send with each code. This differs between manufacturers and, as it turns out they are various. The Table 3.7 gives number of bits of different manufacturer.

Table 3.7: Bits number of different manufacturer

Manufacturer Code	Number of Bits

NEC	32bits
Sony	12or20 bits
RC5	12
RC6	20
Denon	15bits
Motorola	9bits
Samsung	20bits

- **Detection code**

On the signal transmitter side, the script below is uploaded to the ARDUINO NANO:

```
#include <IRremote.h>

IRsend irsend;

Void  loop() {

  irsend.sendNEC (0xFEA857, 32);

  delay (40);

  }
```

The script is described as follows:

- (irsend) object is created from the (irsend) class.

- Then the send NEC method which is in the (irsend) object is used.
- The send NEC method expect two arguments to be passed to, the determined HEX code and number of bits to send with each code (i.e. 32)
- Time period is delayed for 40 ms.
- The void loop will be iterating as long as the ARDUINO is powered.

The signal receiver script is started by including the ir remote library, defining the variables and initiating both (irrecv) and results objects.

The flag is reset to 0 in two conditions: when receiving the referenced HEX code and when disconnection time >= 750mS. And also set to 1 in two conditions when the TSOP is not receiving the referenced HEX code and when the flag itself was 0 then it will be 1 to calculate the disconnection time period.

This disconnection is considered because of the sensitivity of the commercial TSOP 1838. Although when the beam is connected to referenced IR signal the TSOP 1838 receives odd signals. The suggested solution for this issue was to let the decision of (is an object is present or not) to be based on (is the object is present for 750 ms or more?). In similar words ARDUINO waits for 750 ms every time it received the correct referenced signal then determine to trigger/or not the relay.

```
//Include ir remote library by ken sherriff
```

```
#include <IRremote.h>

// define the pins and variabeles

const int RECV_PIN = 7;

const int LED = 13;

const int relay = 5;

int flag;

unsigned long t;

unsigned long interval;

//define ir receiver and results objects

IRrecv irrecv(RECV_PIN);

decode_results results;
```

Then as shown below, the setup function is started by the built-in serial to monitor the received codes, then it is enabled the IR receiver pin 7 to start receiving and demodulating signals. LED and relay pins are set as an output.

```
void setup() {

  // serial monitor @ 9600 baud

  Serial.begin(9600);

  //enable the ir receiver

  irrecv.enableIRIn();
```

```
  flag = 0;
  pinMode(LED, OUTPUT);
  pinMode(relay, OUTPUT);
}
```

Then the loop function that is started by conditional is statement that checks if any coded signal is received, and if so it will be printed on the serial monitor. And assuming a coded signal is received another if statement check for matching with our referenced signal value (i.e. HEX code FEA857). Once matched, flag variable would be reset, indicator led would turn on, and after a time delay of 10 ms pin 5 would set (HIGH), hence triggering the relay.

```
void loop() {
  if (irrecv.decode(&results)){
    //print code in hex
    Serial.println(results.value, HEX);
     if(results.value == 0xFEA857)
    {
      flag = 0;
      digitalWrite(LED, HIGH);
      delay(10);
```

```
    digitalWrite(relay, HIGH);
   }
   else{
    digitalWrite(LED, LOW);
    }
    irrecv.resume();
 }
```

Else statement would be executed if a coded signal is received but did not match the desired reference, this else block contains one command written to turn off the indicating led.

irrecv.resume() method is a part of the parent if statement.

The next code demonstrate else statement that would be executed when no coded signal is received by the TSOP 1838. The block starts with a time delay of 100ms then turning the led off. The checks for the state of the flag and if it equals 1 then the block will be executed. It starts by calculating the difference between the present time and the last time that the ARDUINO got the right signal code (t), then compare the difference with 750ms. Once it's greater than or equal 750ms, the relay will be triggered and the flag will reset.

The lower if block is to determine the start time (t) once our reference signal is not being received. It uses the bult-in function millis() which calculate the beginning of execution time in milli seconds.

```
else{
   delay(100);
   digitalWrite(LED, LOW);


   if (flag == 1){
   interval = millis() - t;
   if (interval >= 750)
   {Serial.println("Object Detected!");
   digitalWrite(relay, LOW);
   flag = 0;
   }
   }
     if (flag ==0) {
     t = millis();
     flag = 1;}
   }
```

```
}
```

The void loop will be iterating as long as the ARDUINO MEGA 2560 is powered.

Setting up the transmitter and the receiver provide a detection system that is reliable for safety purposes.

CHAPTER FOUR

SYSTEM IMPLEMENTATION AND TESTING

4.1 System Implementation

This paragraph illustrates the connection between each of the power supply, power transmitter, receiver and the load.

- An AC/DC converter was used to get 12V dc to supply the power transmitter as shown in Figure 4.1.

Figure 4.1: AC/DC converter

- 50 IR LEDs were fixed on the breadboard, and distributed to 10 parallel branches. Each one of these branches consists of 5 IR LEDs connected in series as shown in Figure 4.2. Every piece needed to 1.2V and 20 mA.
- To each branch, 300 ohm resistance was connected in series, this resistance's value was determined by the Equation 4.1.

$$R = \frac{V}{I} \tag{4.1}$$

Where

R= Resistor of the branch (Ω).

V= Voltage of the resistor (V) = Voltage source – Voltage of IR LEDs.

I= Current of the branch.

$$R = \frac{12-(5\times1.2)v}{20mA} = 300\Omega$$

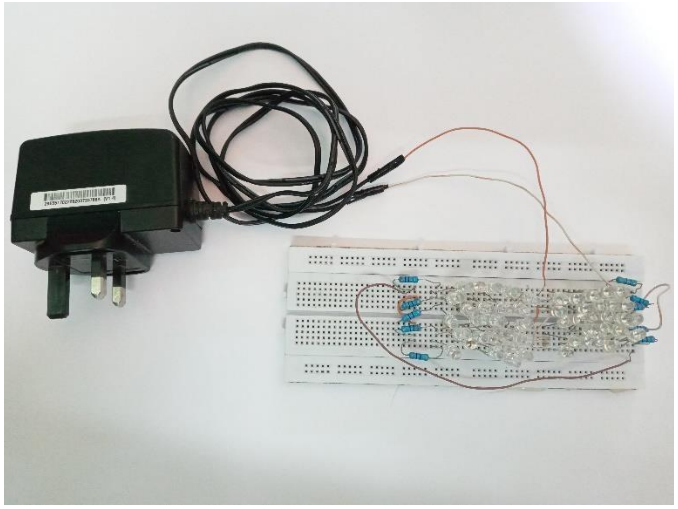

Figure 4.2: IR LEDs matrix

- A photo-electric cell was fixed directing the light source (IR LEDs) as shown in Figure 4.3.

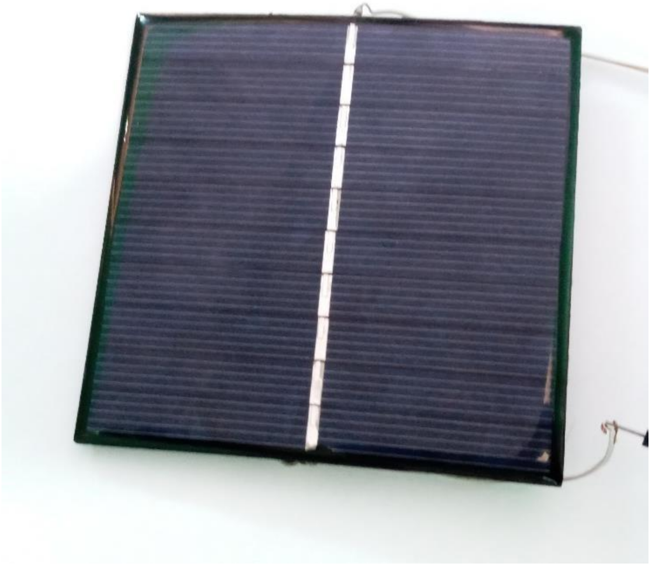

Figure 4.3: Photo-electric cell

- The terminals of the photo-electric cell were connected to USB terminals as shown in Figure 4.4. Then the load (Samsung J105 H) was connected to the USB.

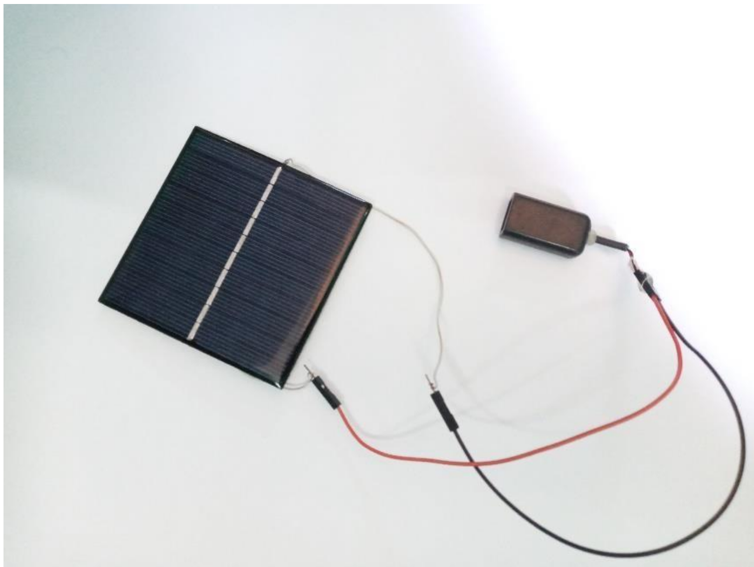

Figure 4.4: USB terminal

- An IR led was connected to the D3 pin in the PWM section of the ARDUINO NANO using a resistance. Then ARDUINO NANO was fixed next to the photo-electric cell, and supplied by an external dc power source (5v) as shown in Figure 4.5.

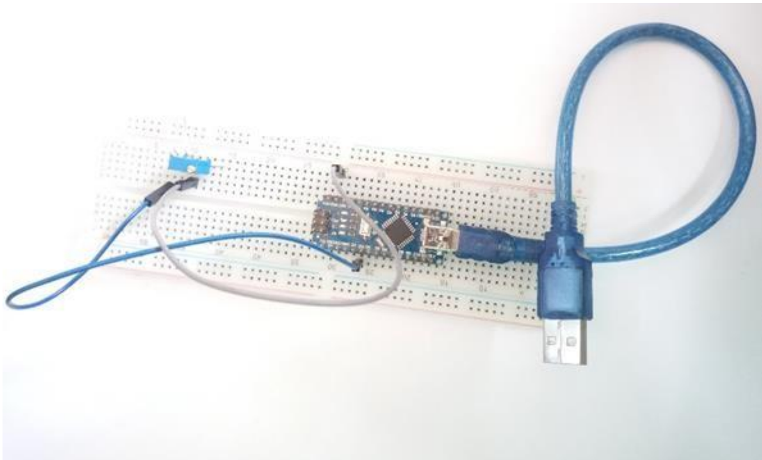

Figure 4.5: ARDUINO NANO circuit

- The positive terminal (line) of the power supply (12V) was connected to a normal-close pin of a relay, and connected to the positive terminal of the IR LEDs circuit. The terminals Vcc, Ground, Signal of the IR receiver TSOP was connected to the pins 3.3, GND, 7 of the ARDUINO MEGA in order.
- The IR receiver was fixed to the breadboard next to the IR LEDs circuit. The pin (5, 5V, GND) of the ARDUINO MEGA was connected to signal, Vcc and ground of the relay respectively. The ARDUINO MEGA was supplied by an external 5v power source as shown in Figure 4.6.

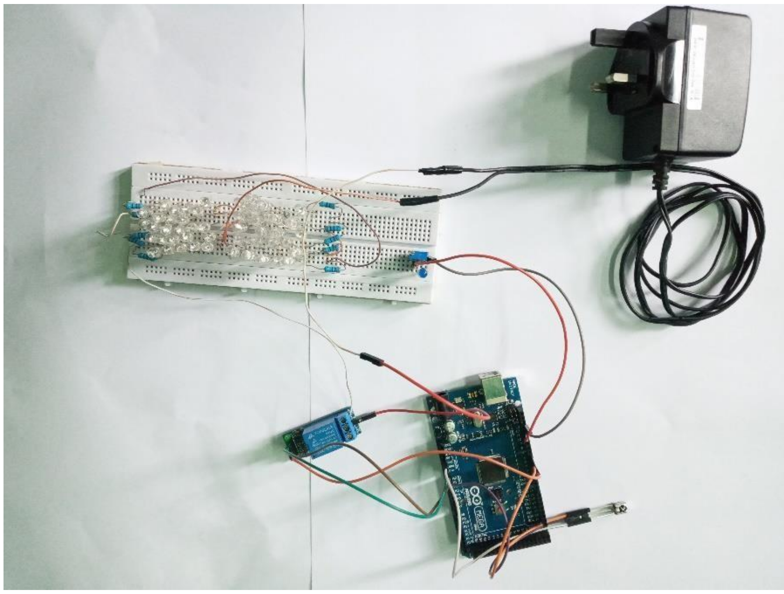

Figure 4.6: Transmitter and controller connection

4.2 System Testing

The experimental testing includes no load test where there is no current being drawn from the receiver, and load test where the mobile phone is connected and started to charge.

4.2.1 No load test

This system was tested at different distances (5-100) cm. The no load voltage was measured at every particular distance. Results as shown in Table 4.1 and illustrated in Figure 4.7.

Table 4.1: No-load test

Distance(cm)	Voltage(V)
5	4.981
10	4.899
15	4.796
20	4.683
25	4.565
30	4.456
35~100	3.876

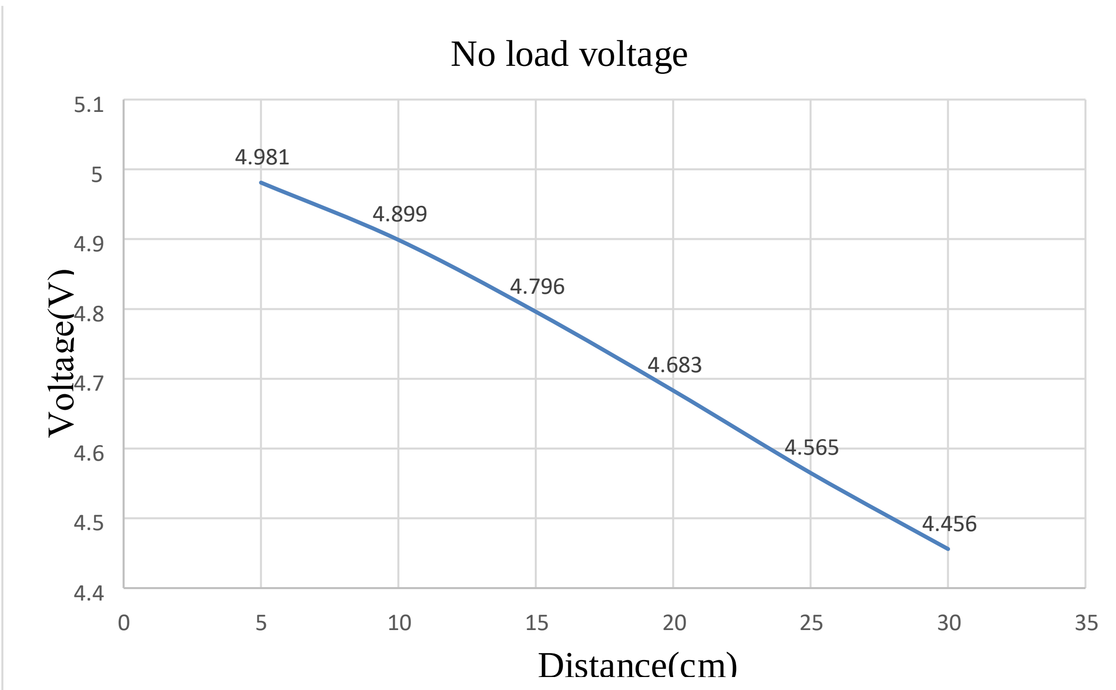

Figure 4.7: No load test

4.2.2 Load test

This system was tested at different distances (5-100) cm. The load voltage and the load current were measured at every particular distance. Results as shown in Table 4.2 and illustrated in Figures 4.8, 4.9, 4.10 and 4.11.

Table 4.2: Load test

Distance(cm)	Voltage(V)	Current(mA)	Power(mW)
5	3.950	3.540	13.983
10	3.880	2.010	7.799
15	3.880	1.750	6.790
20	3.880	1.710	6.635
25	3.880	1.350	5.238
30	3.770	1.220	4.600
35~100	No Charging	No Charging	No Charging

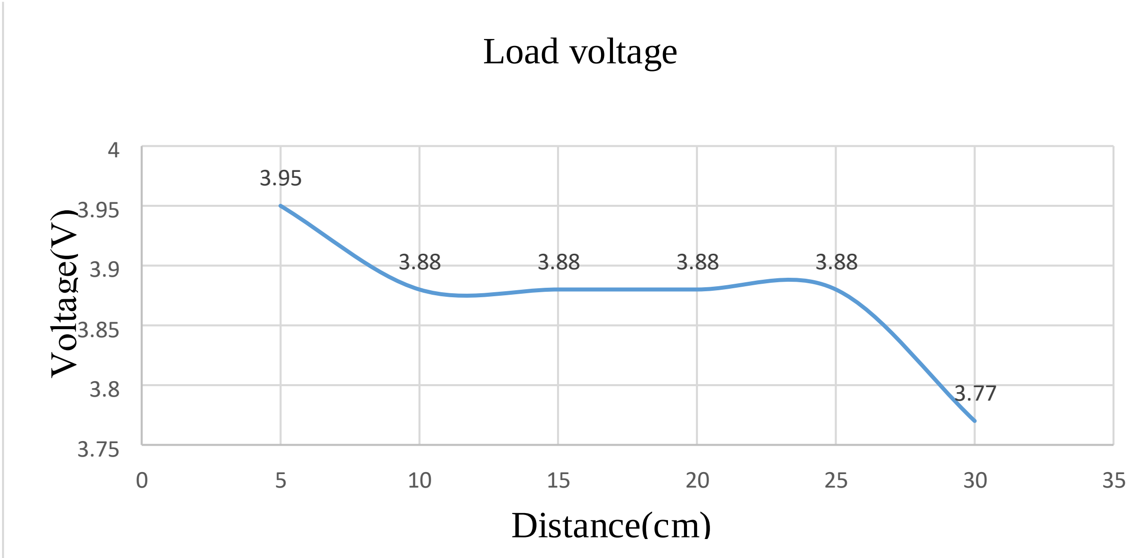

Figure 4.8: Load test (voltage)

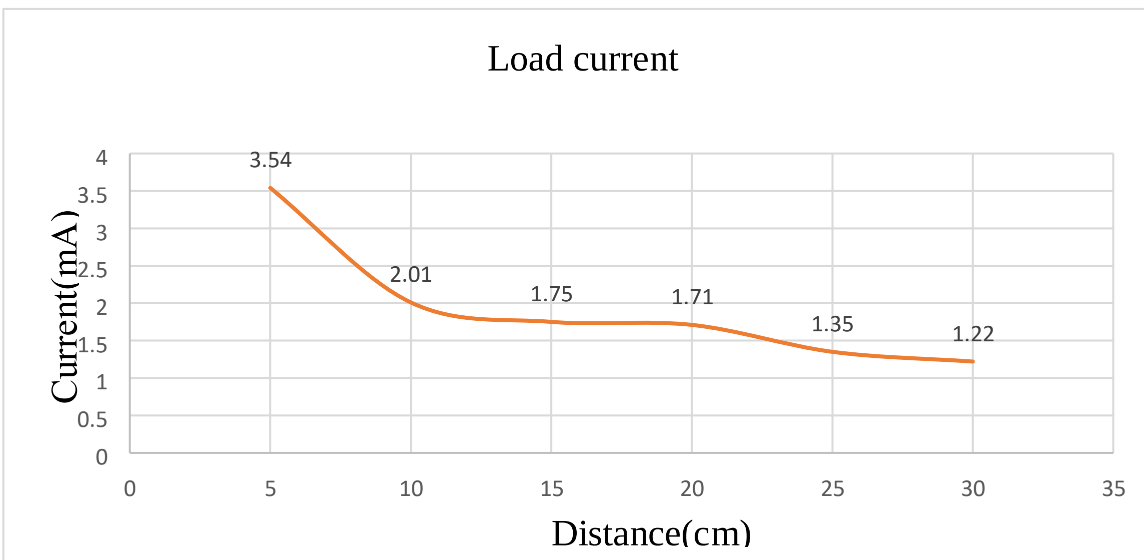

Figure 4.9: Load test (current)

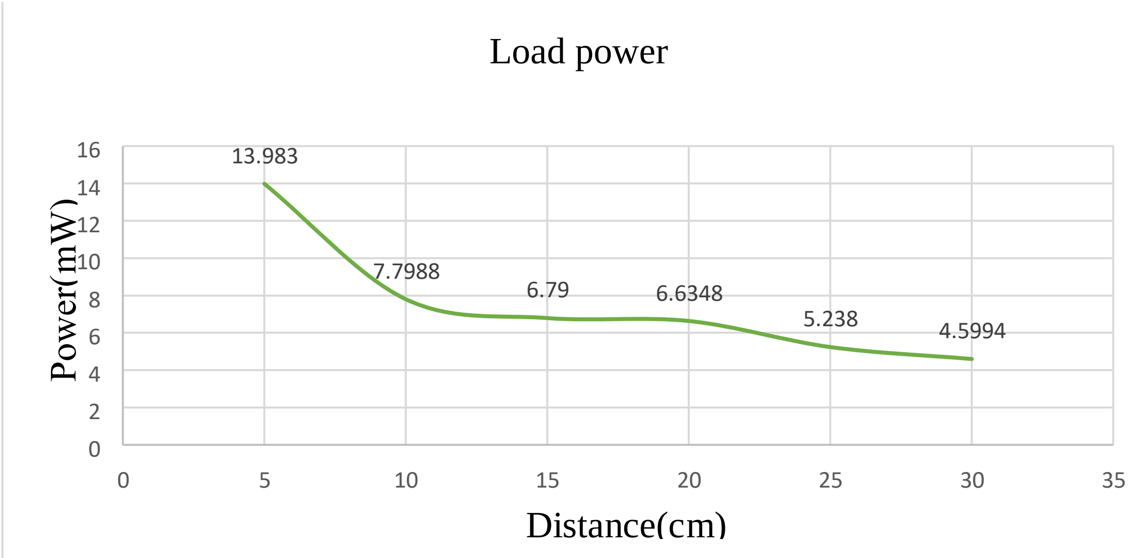

Figure 4.10: Load test (power)

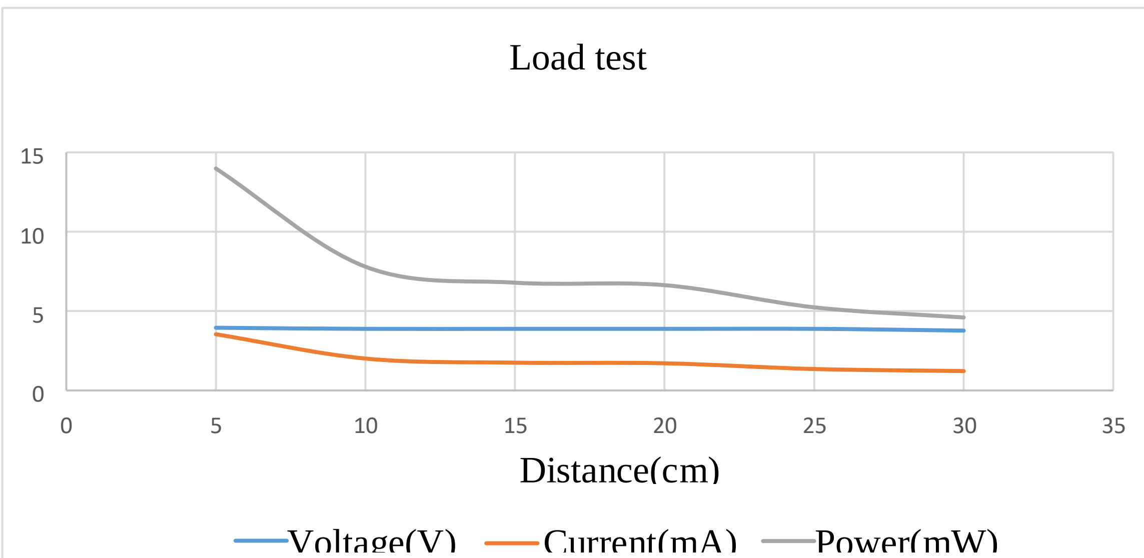

Figure 4.11: Load test all curves

The Table 4.3 shows the results of the no load vs load tests and illustrated in Figure 4.12

Table 4.3: No load VS load test results

Distance(cm)	NO Load Voltage(v)	Load Voltage(v)	Voltage Drop(v)	Percentage Difference (%)
5	4.981	3.950	1.031	20.7
10	4.899	3.880	1.019	20.8
15	4.796	3.880	0.916	19.1
20	4.683	3.880	0.803	17.1
25	4.565	3.880	0.685	15
30	4.456	3.770	0.686	15.3
35~100	3.876	No Charging	-	-

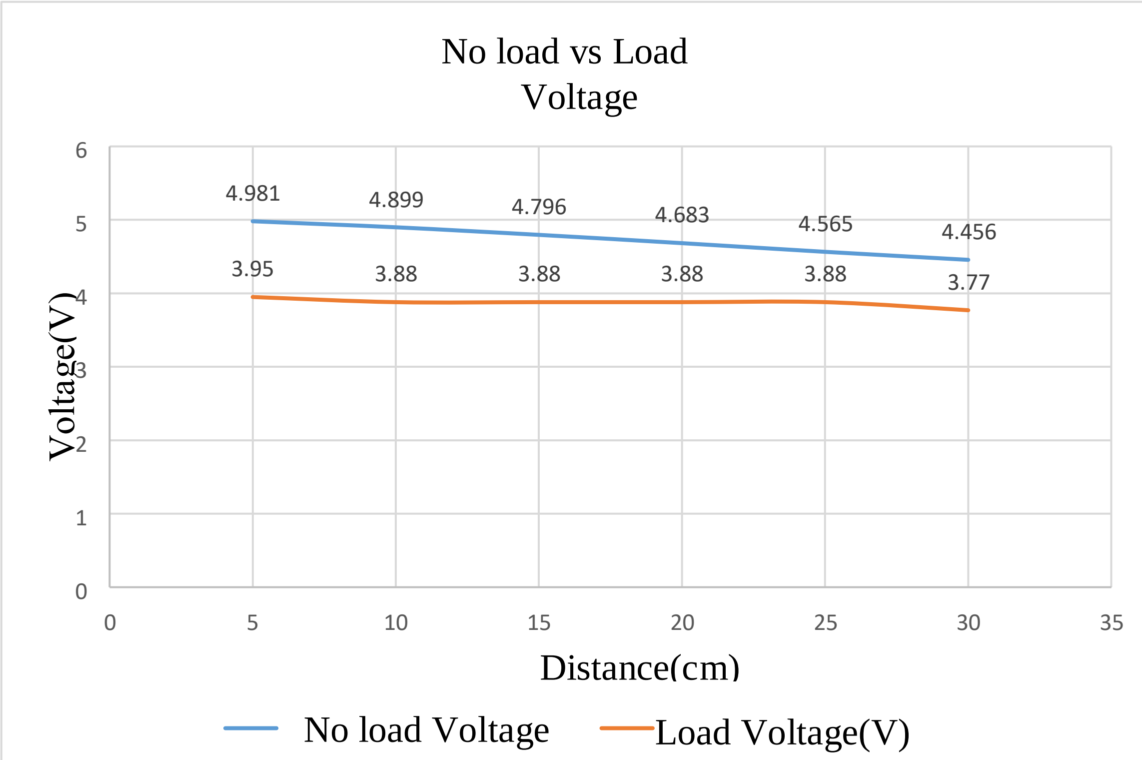

Figure 4.12: No load VS load test voltage

4.3 Discussion

- The system succeeded in delivering electrical power up to 14mW wirelessly.
- The phone was charged successfully despite using commercial IR LEDs.
- The voltage changed linearly with a slight slope due to the chemical nature of the solar cell and the structure of the photodiodes.
- The relation between the distance and the voltage is linear.
- The relation between the distance and the current is logarithmic.

- The relation between the distance and the delivered power is logarithmic (power is the result of multiplying the voltage and the current).
- The voltage loss of the photovoltaic cell when a load is connected ranges between 15% for the nearest distance and 20% for the most far; because of the load's non-linearity nature.
- The mobile phone has charged till 30 cm (between the IR led s and the photovoltaic cell); because the cell's output voltage in a distance further than 30 cm is not enough to charge the phone's battery.
- The output power of the photovoltaic cell depends on the distance from the IR LEDs, the type of the load and its requirements.
- Safety system measures were the same for all the cases, and it was not affected by any external IR source; due to the high reliability of the coded IR signal.
- Detection time was chosen to be 750ms; because this is the shortest period of time in which the TSOP can operate efficiently.
- Load's efficiency for this system is 0.521%. This low efficiency is a result of:

- Using commercial IR led s with 7-14mW output power. This means that the efficiency of the transmitter alone is 29.1%.
- The output light of the IR led s is scattered and not collimated.

- Using commercial photovoltaic cell with max output power 0.2W with the sun’s light, while it has the biggest role in transforming photoelectric power to electric.
- The photovoltaic cell is designed for the visible light.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The primary purpose of the project is to implement a wireless charging system for mobile phones. A charging system which participate in solving the range issue of both wired and wireless charging technologies. In this study, infrared technology has been chosen for the transmission of the electrical power in the wireless form. For Utilizing the range and the efficiency of this technique used in this project, the wireless charger has been successfully implemented and tested. A matrix consisting of IR LEDs has been used in this study as optical power transmitter. The power has been received and converted into electrical form of power via photo voltaic cell which directly connected to the mobile phone. For safety concerns regarding the infrared technology, a detection system has been developed – safety system. The system controls the operation of the optical transmitter and its control decision is made through an electronic circuit connected to ARDUINO controller (mega 2560/NANO).

5.2 Recommendations

The following points can be taken as future works:

- Efficiency of the transmitter can be increased by using high power IR LEDs or IR laser transmitter.

- The overall efficiency can be increased by collecting the optical power in a tight beam of light (reducing the divergence angle).
- The overall efficiency can be increased also by using high performance photovoltaic cells for the conversion of the optical power. An array of MIH® VMJ PV Cell is considered best option for this application.
- The safety system can be further developed by using higher response IR receiver, better quality IR transmitters, and high speed relays (aka solid state relays).

A tracking system can be integrated with the Wireless Charging system. Its primary function will be to scan for the receiver position, point the transmitter to have an acceptable line-of-sight between the transmitter and the receiver, and track the receiver once a movement occurs in a particular range. Tracking feature will guarantee the continuity of power transmission and will provide a comfortable operation experience for the user (charging will not be limited by a fixed position).

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