A Prototype of a Dynamic Wireless Charging System

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***Abstract*—This project designed and developed a proof-of-concept of a dynamic wireless power transfer system using an arduino based microcontroller where the hardware part has been implemented using electronic components and feedback controller software module has been developed in Arduino Uno. The transmitter module converts 9V DC voltage into a high-frequency AC voltage to create a magnetic field around the transmitter coil. The receiver module converts back DC voltage by a full bridge rectifier inverter; the software module manipulates the receiver voltage and provides the user with feedback. Our experimental results demonstrate a successful wireless power transfer with user feedback when the receiver is in motion.**

***Index Terms*—Dynamic Wireless Charging, Arduino Uno, Transmitter, Receiver.**

I. Introduction

Wireless charging, also known as Wireless Power Transfer, enables power transmission without any physical connection between the transmitter and the receiver, where the primary power source transmits electromagnetic energy to a receiver across an air gap by creating a magnetic field [3]. The wireless power transfer has gained interest from both academia and industries since eighteen centuries. This technology attracts a wide range of applications, from low-power bluetooth devices to high-power electric vehicles, because of its convenience and better user experience. Nowadays, wireless charging is rapidly evolving from theories toward standard features on commercial products, especially mobile phones and portable smart devices [1] as it introduces many benefits over the traditional (plugged-in wired charging), i.e., flexibility on mobility, charge on demand, user friendly, etc. Because of its remarkable characteristics of flexibility, position-free, and mobility, the wireless charging technique is becoming an ideal power solution for energizing electric-driven devices [2]. Many phone companies i.e., Apple, Samsung now prefer built-in wireless charging in their newly release phones. Wireless Charging Systems also are gaining popularity in higher power application like electric vehicles over plug-in charging system because of its simplicity, reliability, and user friendliness [3]. There are two form of wireless charging i) Static Wireless Charging System(SWCS) and ii) Dynamic Wireless Charging System (DWCS). However, the limitation of static wireless charging system is that the receiver needs to wait at dedicated charging station which is time consuming. Moreover, stationary SWCS have some challenges, such as electromagnetic compatibility (EMC) issues, limited power transfer, bulky structures, shorter range, and higher efficiency. The dynamic nature of wireless charging has solved the issues with static wireless charging. Dynamic wireless charging has wide application in transportation, especially in electric vehicles. The dynamic wireless charging allows a receiver to get charged its battery while it is in motion. However, dynamic wireless charging has to face issues like large air gap and coil misalignment. In other words, the efficiency of the power transfer in the dynamic wireless charging system primarily depends on the coil's proper alignment and small air gap. The average air gap distance between the transmitter and receiver coil is between 150 to 300 mm for small passenger vehicles. Hence, proper alignment of the coils and keep small air-distance increase the efficiency of wireless power transfer.

In this project, we will design and develop a proof-of-concept prototype of a dynamic wireless charging system to demonstrate that wireless power transfer is possible while the receiver is movable. The highlighted part of this projects are

- Design wireless power transmitter circuit with transmitter coil
- Design power receiver circuit with the receiver coil
- Develop a software module on Arduino Uno based on ATmega328P microcontroller

We organized the rest of the report as follows. In section II, we discussed some existing works on microcontroller based wireless power transfer systems. We introduced our problem statement and discussed a general overview of the project in section III. In section IV, we talked about implementation details and section V contains results of our implementation. In section VI, we discuss the challenges we faced during the implementation of this project. Finally, section VII contains a summary discussion and future scope of work.

II. Related Works

Ding et al. [5] designed a microcontroller-based mobile wireless charger to adapt wireless charging in medical devices, sensors, municipal transportation, and other applications. The author used a low-power microcontroller STC12C5A60S2 to monitor and control wireless charging activities, e.g., voltage control, control. They also used low-power LCD1602 to display charging voltage and current. Swarnalatha et al. [6] proposed a prototype for Wireless Charger based on Rectenna and Atmel Microcontroller using microwave wireless communication. The use of the ATMEL microcontroller is simple and straightforward. It reads digital data received power by the Rectenna converted into digital form by ADC and converts into an output voltage and displays the charging status and voltage in the LCD monitor. Zaw et al. [7] developed a wireless mobile charger design based on inductive coupling using Arduino

Uno with ATmega328P microcontroller. In this project, the author used the ATmega328P microcontroller to use pulse width modulation (PWM) from the microcontroller to drive MOSFETs and show produced voltage in a 12C LCD in both the receiver and transmitter so that the user can adjust the input frequency. The author of [8] proposed a microcontroller-based wireless power transfer for electric vehicles implemented using an Arduino microcontroller, inductive coils, and vehicle prototype module. The Arduino microcontroller controls the power supply switching and is also used to generate pulse signals to the inverter through the driver and voltage regulator.

However, no existing works designed a microcontroller-based prototype of the dynamic wireless charging system. We create a proof-of-concept prototype of a dynamic wireless charging system based on ATmega328P microcontroller-based Arduino Uno.

III. Problem Statement

Wireless power transfer is an emerging technology where a receiver receives energy without physical contact. There are two primary components in a wireless charging system, i.e., the transmitter coil, which transmits power, and a receiver coil that receives charges by a mutual coupling or inductive coupling. Two types of wireless charging system have been found, i) Static wireless charging system (SWC), where the receiver has to remain stationary at the charging station while it is charging, and II) Dynamic Wireless Charging System (DWC) where the receiver gets charged while in motion.

This project aims to develop a simple proof-of-concept prototype of a dynamic wireless charging system to demonstrate that it is possible to charge devices in motion. More specifically, we will develop power transmitter and receiver parts using electronic components and a development kit (Arduino with **ATmega328P micro-controller**) has been used to monitor and display the charging status in real-time. The user can provide feedback to adjust the parameters of wireless charging and see the feedback in real-time as an output. Fig.1 shows the block diagram of a prototype of a dynamic wireless charging system. This system consists of i) a power supply which can be dc or ac supply, ii) a compensation network which will convert dc/ac supply to high frequency AC supply, iii) transmitter coils and on the receiver side, i) a receiver coil, ii) a compensation network(rectifier bridge) and finally ii) loads. The power is transferred via mutual induction created by transmitter and receiver coil primarily using magnetic resonant induction, i.e., the transmitter coil creates an electromagnetic field, and whenever the receiver coil is closed to the transmitter coil, a mutual induction field is created. Hence, the power is transferred.

IV. Implementation

Since the project is an Embedded system based project, there have software and hardware component assembled together. The software part is a module to get real-time feedback

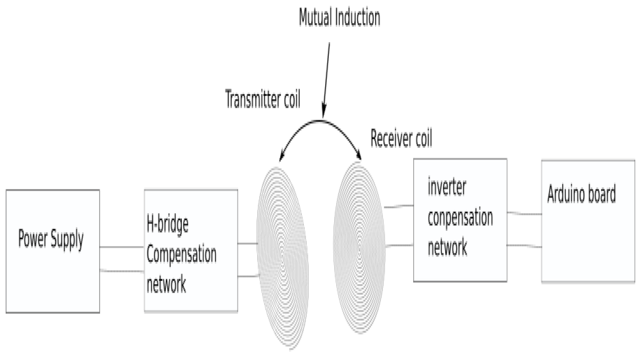

Fig. 1. General block diagram of a dynamic wireless charging system

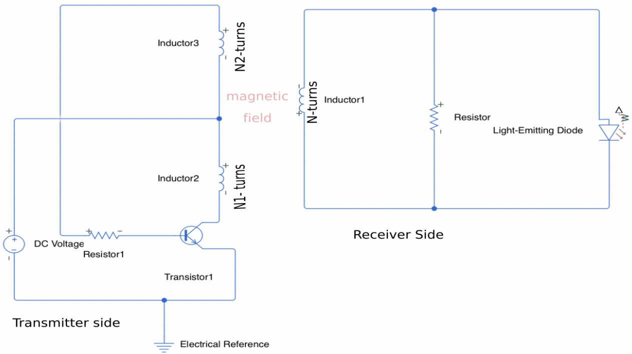

Fig. 2. Equivalent circuit diagram of the wireless energy transfer

for the users and the hardware components for actual prototype development for the dynamic wireless charging system. The implementation phase includes i)design power transmitter module, ii) design power receiver module, iii) assemble power receiver module with Arduino Uno, and iv) develop software module to get output results for user feedback.

A. UML Diagram

The Unified Modeling Language (UML) is a tool for visualizing, specifying, constructing, and documenting the software and system artifacts [10]. The UML has started emerging in the mid-1990s in the object-oriented analysis and design (OOAD) approaches. The has been accepted as the standard for object-oriented design and the engineers are still practicing [9]. The UML diagrams for the proof-of-concept prototype of a dynamic wireless charging system have been designed and presented here.

B. Hardware component

1) Coil: Coil is one of the crucial parts of wireless power transfer system. For wireless power transfer, there are two coils; a receiver coil and a transmitter coil. For this project, BENTECHGO 26 AWG enameled copper wire of diameter of 0.0157 inches which can tolerate 155°C is used.

2) Power Source: To provide power supply for this project a single 9V DC battery from Duracell company has been used

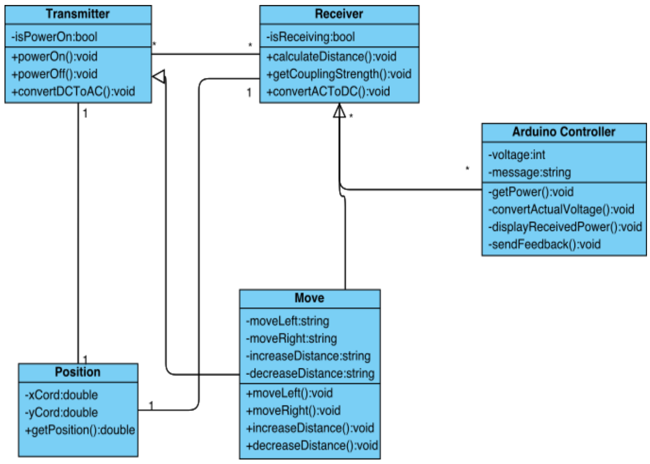

Fig. 3. Class diagram of the dynamic wireless charging system

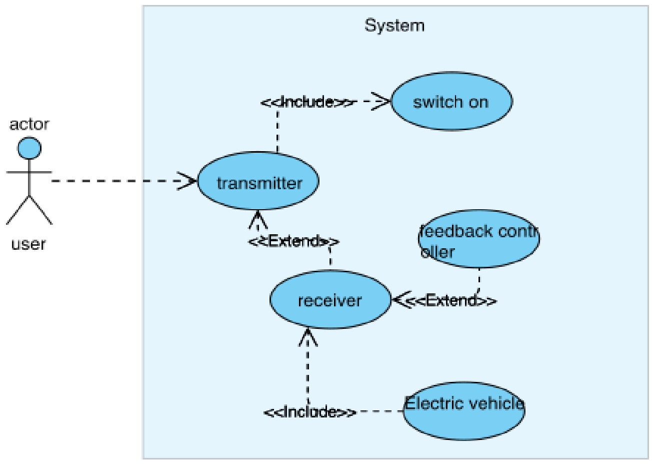

Fig. 6. Use case diagram of the dynamic wireless charging system

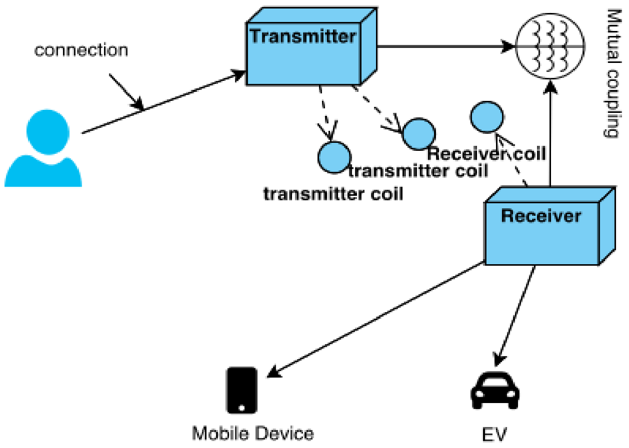

Fig. 4. Deployment diagram of the dynamic wireless charging system

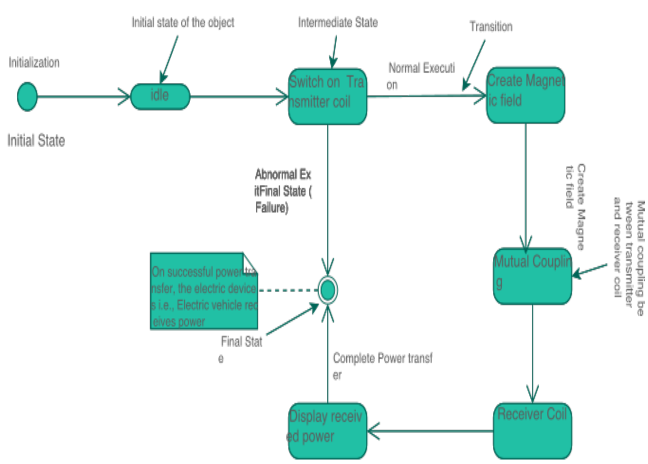

Fig. 7. State Chart diagram of the dynamic wireless charging system

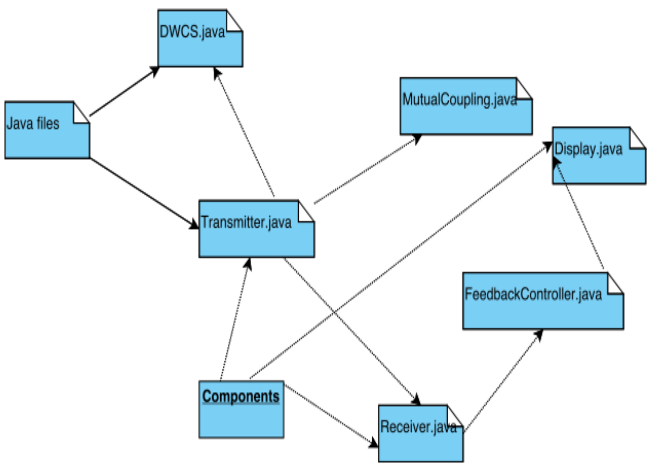

Fig. 5. Component diagram of the dynamic wireless charging system

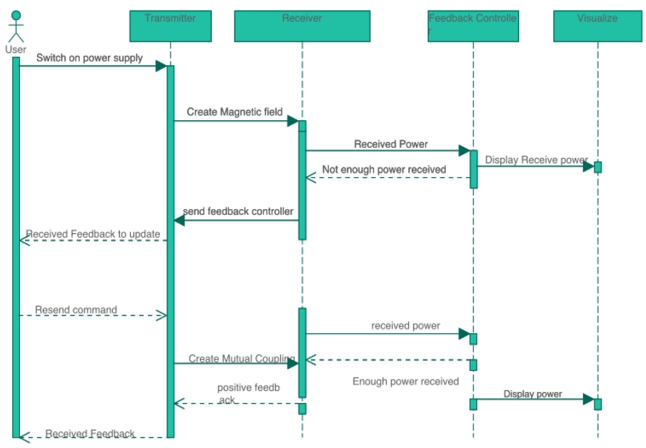

Fig. 8. Sequence diagram of the dynamic wireless charging system

which is sufficiently enough to demonstrate the functionality of wireless power transfer system.

3) Resistor: 5 300Ω resistors have been used to reduce the current flow through the circuit so that circuit does not burn out.

4) MOSFET: A metal oxide semiconductor field effect transistor (MOSFET) is used to amplify voltages in circuits. In this project, 2 **IRFZ44N** mosfets has been used. The IRFZ44N is a N-channel MOSFET which has a high drain current of 49A and voltage of 55V. It starts conducting at voltage over 4V. Hence, it is commonly used with microcontrollers to drive with 5V

5) Rectifier Diode: A diode is basically used to allow current to pass only one direction. In this project, 4 1N4007 Schottky Rectifier Diodes have been used.

6) Arduino Uno: An arduino uno with **ATmega328P** has been used to implement software section of the code. The board has 14 digital pins(input/output) and 6 analog pins to read analog input.

7) LCD Display: A 16 pins LCD display has been connected with arduino uno board to monitor the receiver voltage by the receiver coil.

8) Capacitor: A 50 μF has been used in the receiver circuit. A capacitor can store energy and work as power source when necessary. Sometimes, a capacitor can work as filter as well.

9) LED: A few LEDs have been used in this project. LEDs indicate proper functionality of the dynamic wireless charging system and is also useful for the user feedback.

Two important parts of a wireless charging system are transmitter side and receiver side. The transmitter consists of main power supply, some technologies to convert low input voltage into high frequency AC current and importantly transmitter coils. For dynamic wireless charging system, there are multiple transmitter coils spread over the surface i.e, underneath the road surface in electric vehicle so that if the receiver moves, it can receive the power. The transmitter coil creates magnetic field when current passes through the coil. The receiver consists of a receiver coil and a load in its simplest form. Whenever the receiver coil is placed over or nearby the transmitter coil, a mutual induction has created between the coil because of electromagnetic field. However, the coil geometry may be different in sizes and shapes [4].

C. Hardware Implementation

The hardware implementation can be divided into three main parts; power supply, receiver circuit, and transmitter circuit. The receiver circuit integrates an Arduino-based microcontroller hardware implementation to implement the software parts for user feedback and control. The general block diagram is shown in Fig. 1 and Fig. 2 shows a simple circuit diagram of wireless power transfer system.

In the power supply section, we use a 9V DC battery to power up the transmitter section. Since this project aims to design a proof-of-concept of a dynamic wireless charging system, a 9V battery is sufficient to produce the power required by the project. A half-way DC-AC converter has been designed, which converts direct current (DC) into a high-frequency alternate current (AC) using the metal oxide semiconductor field-effect transistor (MOSFET) of the IRFZ44N model. The output of the converter is connected with the transmitter coil. The transmitter coil plays a crucial role in the wireless power transfer system.

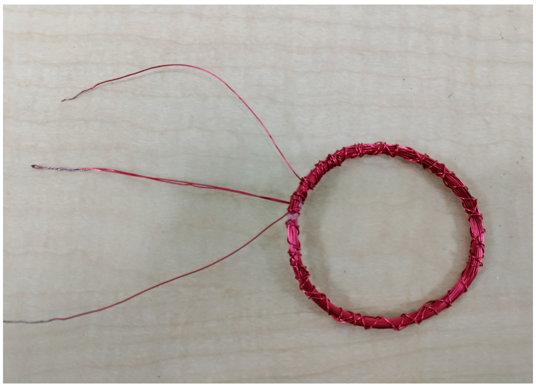

Fig. 9. Transmitter coil

We design three circular shape coils for the transmitter, which have an approximate diameter of 6.0 cm of each coil using 26 AWG magnet copper wire. Fig. 9 shows a transmitter coil. Each coil has three sections to connect with the transmitter circuit designed as winding 20-turns, then a loop for the center tap connection, and again a wind of 20-turns. Thus, each coil has a circular shape of 40-turns. Finally, multiple transmitter coils have been integrated into the transmitter section in order to get the dynamic nature of the wireless charging system.

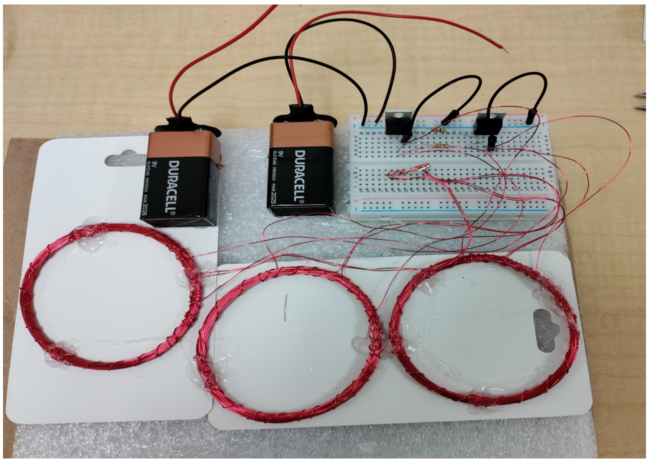

Fig. 10. Hardware Implementation of the Transmitter section

Fig. 10 shows the transmitter section's hardware implementation, and Fig. 11 shows an equivalent circuit diagram of the transmitter. In the transmitter coil, the MOSFET bridge produces a high-frequency alternate current (AC) across the coil and generates a magnetic field around the transmitter coil. Since the coil has looped at the center, the two sides of the coil are connected to the MOSFETs' drains, and the center tap is connected to the battery's positive terminal, which eventually starts to charge up the coil. MOSFETs also discharge the inductor since the source of the MOSFETs is connected to the ground. The charging and discharging produce a very high-frequency oscillation signal which creates a magnetic field around the transmitter coil.

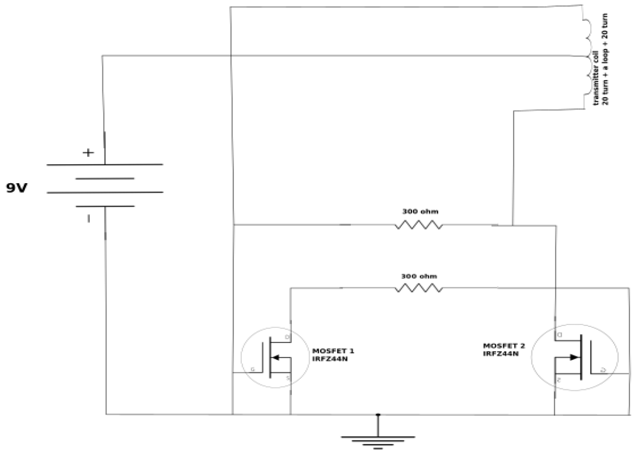

Fig. 11. An equivalent circuit diagram of the transmitter

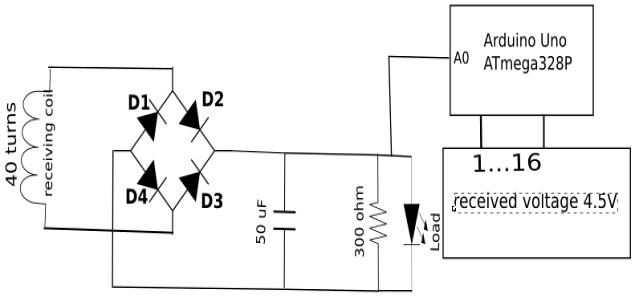

Fig. 12. Equivalent circuit diagram of the receiver

The receiver part consists of a receiver coil, a full rectifier bridge, a capacitor, and an Arduino board. The receiver coil is slightly different than the transmitter coil. It has only two points and shown in Fig. 13.

Fig. 13. The receiver coil

The power is transferred from the transmitter coil to the receiver coil whenever the receiver coil is in the range of the magnetic field created by the transmitter. The distance between the transmitter and receiver influences the amount of energy received. If the distance is too high, the receiving efficiency decreases. The efficiency is maximum when the distance between the receiver and transmitter is zero. The receiver current is high-frequency AC from the transmitter. A full-wave rectifier bridge has been used to convert AC voltage into DC voltage so that load or other devices such as Arduino can use it.

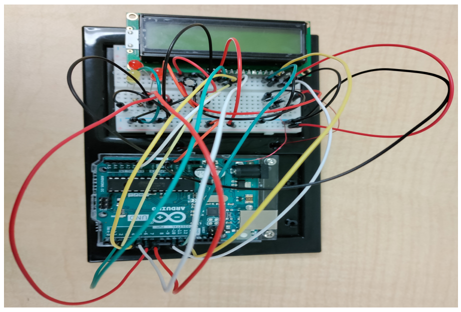

Fig. 14. The receiver hardware implementation (front view)

Fig. 12 shows the equivalent circuit diagram of the receiver. Fig. 14 shows the hardware implementation for the receiver, which is implemented using the Arduino Uno, breadboard to design rectifier circuit, and attached LCD.

Fig. 15. The receiver hardware implementation (back view)

Fig. 15 shows that the power receiving coil has been attached beneath the receiver circuit board that helps ease the receiver circuit's movement when the receiver is in motion.

D. Software Implementation

The software module has been developed based on Arduino Uno, which has an ATmega328P 16MHz microcontroller. Fig.16 and Fig.17 show the implementation of the software module. The software module works as a feedback controller to the users to get real-time feedback on the received power from the transmitter. Based on the feedback information the user received, he/she will update the coil alignment, air-gap distance, etc. For feedback control, we use light-emitting diodes (LEDs) light. It has three LEDs. One red light indicates whether the power is transmitting to the receiver. This can be checked by looking at the LEDs as if the receiver receives power; the LED will remain on and vice versa.

The Arduino Receives analog voltage on port A0 and converts it in the range of 0-5 volts. For feedback, we use two LEDs, one is red, and another is yellow. We have set a threshold of 2.5 volts to give proper feedback to the users. If the receiver receives voltage below or equal to 2.5 volts, this indicates that the transmitter and receiver coils are not in

```
DWPT
/*
**  Software module to get user feedback based on received voltage
*   fromm the receiver coil. The sole purpose of this software module
*   is to get up-to-date voltage measurement if user changes/moves
*   the reveiver coil.
**/

/*
** Initialize required libraries
**/
#include <LiquidCrystal.h>

#define PIN_12 12
#define PIN_11 11
#define LCD_BLACK_LIGHT 10
#define PIN_5 5
#define PIN_4 4
#define PIN_3 3
#define PIN_2 2

LiquidCrystal lcd(PIN_12, PIN_11, PIN_5, PIN_4, PIN_3, PIN_2);

float readingVoltage = 0;
int sensorPin = A0;
const int LED_PIN_RED = 6;
const int LED_PIN_YELLOW = 7;
void setup() {
  // put your setup code here, to run once:
  lcd.begin(16,2);
  lcd.print("Receiver Voltage output");
  Serial.begin(9600);
  pinMode(LED_PIN_YELLOW, OUTPUT);
  pinMode(LED_PIN_RED, OUTPUT);
  pinMode(LCD_BLACK_LIGHT, OUTPUT);
  analogWrite(LCD_BLACK_LIGHT, 128);

}
```

Fig. 16. User feedback software module(Part1)

```
void loop() {
  // put your main code here, to run repeatedly:
  lcd.clear();
  readingVoltage = analogRead(sensorPin);
  Serial.print("Received Voltage: ");
  readingVoltage = 0.0049*readingVoltage;
  lcd.print("Rece. Volt. ");
  //lcd.setCursor(1,1);
  lcd.print(readingVoltage);
  Serial.println(readingVoltage);
  if (readingVoltage <= 2.50){
    digitalWrite(LED_PIN_RED, HIGH);
  }
  if(readingVoltage > 2.50){
    digitalWrite(LED_PIN_YELLOW, HIGH);
  }
  delay(1000);
  digitalWrite(LED_PIN_YELLOW, LOW);
  digitalWrite(LED_PIN_RED, LOW);
}

Done uploading.
```

Fig. 17. User feedback software module(Part 2)

proper alignment or the air distance between the two coils is very long. However, if the yellow LED is on, that indicates that two coils are in close enough. Hence, no update is required. The users also can see the printed output from the serial monitor in real-time.

V. Experimental Result

For the experiment,we build a simple prototype of a dynamic wireless charging system using microcontroller based Arduino board, electronics components, and software feedback controller. The experimental results show the successful implementation of a dynamic wireless charging system.

Fig.18 demonstrates the successful wireless power transfer system. The output voltage is showing $4.0V$ which is nearly

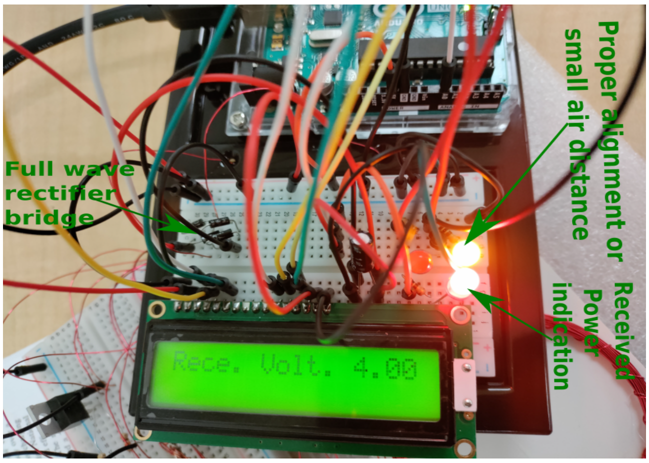

Fig. 18. Received voltage at proper alignment and small air distance

maximum on the LCD display when the alignment is nearly proper and air distance is minimum. It also show visual feedback to the users. When the yellow LED is on, it indicates the coils alignment and air-gap is sufficient. There is another LED indicating by arrow (received power indication) which tells whether the system is working or not. Fig.19 shows

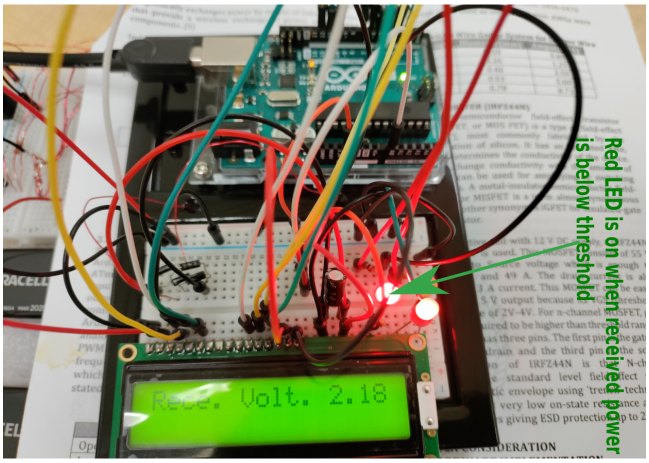

Fig. 19. Received voltage below threshold

that the implemented wireless charging system is capable to transfer power if there is an insulator between the transmitter and receiver coil. Here, we have used a four folds paper shown in Fig.21 between the transmitter and the receiver. However, the receive voltage is below the threshold and red LED is on which provides the users with feedback that the distance between coils might be high. Fig.20 also demonstrates that our prototype design is capable transfer power if there is plastic insulator. However, the efficiency of the transmitter and receiver may decrease because of the insulator.

Fig.22 and Fig.23 demonstrate the Arduino serial monitor output of received voltage from the receiver. It also demonstrates that when the coil's alignment and air gap is not in proper, the efficiency would hamper. However, It also

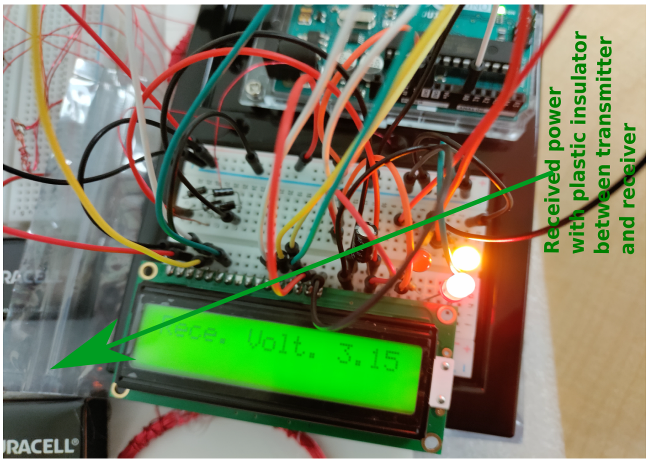

Fig. 20. Received voltage with plastic insulator

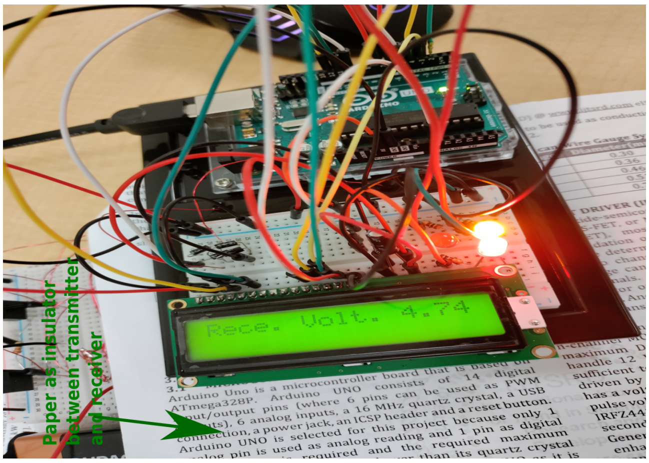

Fig. 21. Received voltage with paper insulator

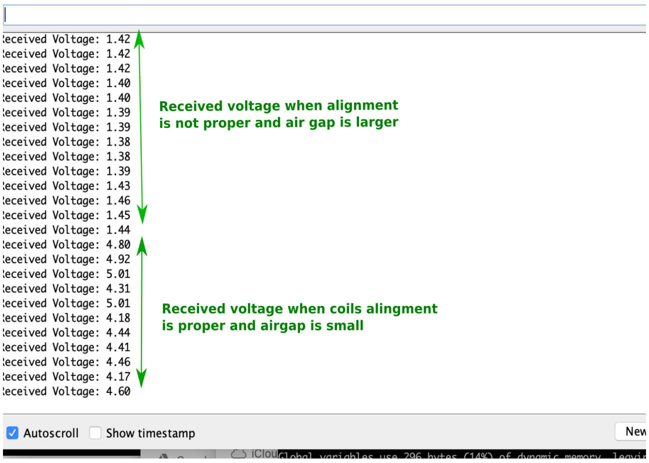

Fig. 22. Received voltage output in serial monitor

demonstrates improve efficiency when the alignment and air distance is small. The power receiving efficiency will vary if the receiver moves as it is because of coil's displacements and change of air distances.

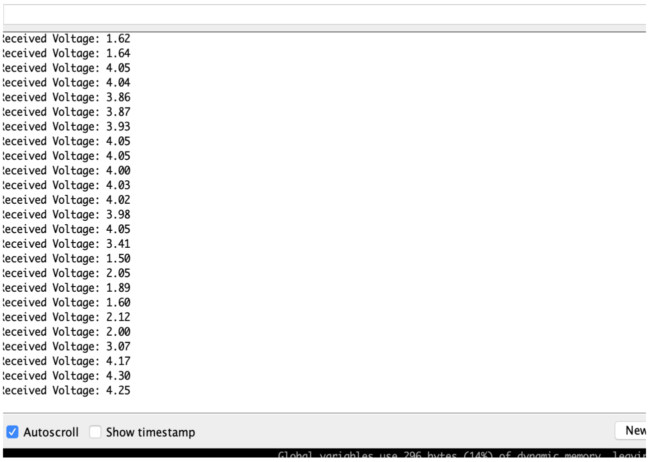

Fig. 23. Received voltage output in serial monitor

VI. Implementation Challenges

This project requires a lot of Electrical background. Initially, it was tough for me. The challenges I have faced during the implementation of this project.

- Limited Electrical Background. I have to spend a sufficient amount of time to have basic on electronics
- Previously, I have not used Arduino to do any embedded system projects. I have learnt it through tutorials and examples.
- Choosing appropriate components is also challenging task. Initially, I have used npn-transistor to implement transmitter. Unfortunately, it was not working. I found a solution of it using MOSFETs instead of transistor.
- Coil design is also an important factor here. Coil wire thickness and diameter play an important roll in the efficiency of the wireless power transfer.

VII. Conclusion

This project presented a proof-of-concept of a dynamic wireless charging system. The project is divided into three main parts; transmitter, receiver, and feedback controller. The hardware part is implemented using electronics components, and the software part is implemented using ATmega328P microcontroller-based Arduino Uno. The results show the successful implementation of dynamic wireless power transfer with feedback for the users. A further improvement of this project can be made by adding Arudino based controller to detect the movement of the receiving object. Controlling transfer efficiency using Arduino would be a future extension of this project.

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