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Wireless power transmission of mobile robot for target tracking

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ABSTRACT

The system is novel approach to combine wireless power transmission system (WPT) and automated guided vehicle (AGV). The wireless power transfer for charging the mobile robot is implemented using inductive coupling method. The system setup consists of transmitter coils whose switching action is controlled through transistors, receiver coil connected to full ridge rectifier and mobile robot. The track consists of number of transmitter coil which transmits power in form of electromagnetic waves. The receivers in the robot, which receives these waves and converts it back to electric power to charge the battery. The robot tracks its target destination based on the user command from the smart phone through Bluetooth. Very few theoretical researches are available on this field. A prototype was developed and tested based on the researches. The system achieves good range but falls short in efficiency to charge a battery, charging of battery takes longer time than regular charging time. Further research and extensive exploration can bring this technology from theory to practice.

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1. INTRODUCTION

In the for-seen future it will mostly be driven by the cutting-edge technology of wireless power transmission (WPT). Since it may sound simple to hear that, it removes one item in the list which is wire to transfer the power. But it is quite complicated than it sounds, it uses air as a medium using electromagnetic waves to transfer the power. However, it has the transmitter, receiver coils but which may not have a direct contact with a minimal distance in-between. WPT becomes an added advantage in the situation like in hazardous areas and human inaccessible areas. The key advantage in the wireless power transfer is that its maintenance free which provides the benefit of using this in tough environments like dirt, ice, water and chemicals which does not affect the transmission [1]. As the benefits it has its own disadvantages the power loss is more in this and low distance power transmission only it is effective. Some examples like wireless charging mobile phones, electric tooth brush. It can be introduced in the electric bikes for charging that surely reduces the clutter of wires in the charging [2]–[4]. It is been used in certain technologically developed countries but the installation cost is high. But compared to solar vehicles where the size of the attachment is big, this is not the case in the WPT systems. Developing the circuit for the WPT system is quite difficult since it needs to convert AC-DC to charge the battery [5]–[7].

Khutwad and Gaur [8] has defined the challenges in wireless charging which deviates from traditional concept of charging. Inductive coupling is used in this paper to transfer the power from the transmitting to the receiver coil and the switching is triggered by the metal oxide semiconductor field effect transistor (MOSFET) present in the circuit which detects the presence of the vehicle. Direct current–alternating current (DC-AC) conversion is done which is used to transmit power at lower frequency. As the AC signal is been generated at the primary is transferred via induction to secondary and further it is converted to DC using rectifier and which charges the battery. Liquid crystal display (LCD) is used to display the output current received; the voltage is stabilized using high voltage DC supply. The efficiency of the circuit is about 67% at a distance between coil been 6 cm. For high quality performance the most common microcontroller PIC16F877 with 40 pin configuration is used.

Shidujaman *et al.* [9], has developed a robot with the most commercial products that are present in the market like QI transmitter plate and a receiver. The robot which has a holder in the top where the tray holds the mobile phones, and meanwhile the holder is been connected to the QI receiver plate. This receiver plate is powered by the transmitter plate which is connected to the power supply and the robot moves based on the need of the charge demand of the persons. They have the sensory sensors like touch sensors and ultrasonic sensor for the obstacle avoidance [10].

Valenta and Durgin [11] has provided a theoretical outline and mathematical derivations. It has discussed the basic types present in power transmission like the near and the far field WPT. It also discusses the key components and the effect of change of the power in different components like antennas, band pass-filter, power generator and band pass filter circuit, also about the sources like microwaves by magnetron, RF power transmission by solid state devices like MOSFET and insulated gate bipolar transistor (IGBT). The major defects like the threshold and reverse-breakdown voltage where the losses are high, and also at the receiver side there is an impedance matching loss which reduces the power efficiency. Various topologies of sources for the power harvesting techniques were detailed dealt by many researchers [12]–[14].

Kim *et al.* [15], has made detailed experiment on the WPT system with frequency tracking and power transfer control with an optimized levels using a half bridge resonant converter. They boosting their efficiency to 67%. They used a 30 W. It consists of a transmitter with a 3.7 W to transmit the power and receiver side has a light emitting diode (LED) load as indicators. They have tabulated the two different frequencies and calculated the gain values. The two MOSFET in the circuit acts as a resonating circuit which is used to create the sine wave by switching continuously which provides the desired wave form, which is AC in nature. Thus, they have transmitted power wirelessly with the above circuit. Few other researchers have experimented the WPT system half bridge resonant converter along with tracking the frequency and associated with a control unit having optimized power transfer.

This paper aims to create a prototype of a mobile robot which moves wirelessly charged in a confined space like industry and warehouse. As the technology advances the application is been upgraded from the wireless mobile phone chargers to the advanced version to use them in automobiles [16]–[18]. This work is an initiative to amalgamate the two concepts like WPT system with AGV [19]. The whole concept is to recharge the battery of the robot while it's in motion using WPT system. The robot will navigate in a preplanned path, the power supply is fed to the multiple transmitter coils that are present in the track [20]–[23]. There is rectifier circuit present on the robot which converts and it uses the source to charge a battery, while the other battery powers the robot. The two batteries are being switched by a relay circuit. The robot navigates to the three different locations as prescribed in the pre-planned path based on demand. It receives a signal or a message using a HC-05 blue-tooth module, so it can move to the demanded position. In this work, the signal is sent to the module via phone as shown in Figure 1.

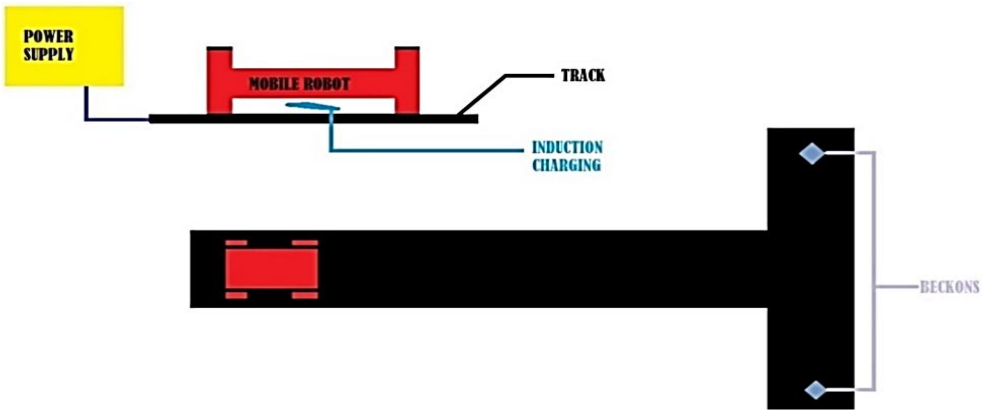

Figure 1. Conceptual diagram of wireless power transmission

2. BACKGROUND

2.1. Wireless power transmission

As far as WPT it is classified into two major categories near-field and far-field. As the name indicates that the power can be transmitted within a short distance of approx. within 50 cm. It uses two basic types: i) Inductive coupling-In this the coil is energized and in turn creates a magnetic flux. As in the working of transformer change in the magnetic flux in primary which when placed near to a secondary coil will create a small induced emf; and ii) Capacitive coupling-It is the same concept in this also but only one variant is that, it uses plate instead of coils. As compared to the near-field the far-field covers over a longer distance, but it uses other sources like radio waves, light waves, microwaves. In these cases, the transmitting sources are the RF transmitter, laser and at the receiving end it is captured by RF receiver and a photo-diode in case of a laser.

2.2. Automated guided vehicle

As technology advances the AGV could create a revolution in the industrial sector since conveyor belts can be replaced by the AGV. They navigate based on the concepts like mapping and machine vision. They can be used in the repetitive environment like part, product handling and in loading parts which reduces the human effort. It has an added benefit since it can handle wide range of weight, from light to heavy weights. AGV can be used in many sectors like warehouse, inside nuclear reactors for servicing, manufacturing, and theme parks to guide people.

2.3. Path select mode

In this mode, the pre-planned path is used by the mobile robot based on the command received. The command is converted into numeric values which are done by micro-controller and it matches with the decision already programmed by the user. AGV reaches the appropriate position based upon the decision. It is quite simple method which reduces the complexity of programming.

2.4. Challenges in the existing system

The main drawback in WPT is that the object must be stationary in order to charging to be achieved, which increases the potential drawbacks like charging time that is higher than the usage time, even though the paper gives a limited insight for creating robot to be able to move in a constrained track which is considered as a novice initiative. This paper has great potential in changing the future automation and robotics field. This is because it can be used in different areas like manufacturing, for movement of products from the factory to warehouse, in transport facilities like airport, railways for carrying luggage and transport of goods. As the trend to electrical vehicles is increasing, it can be used by laying tracks on roads [24]–[27]. The traditional charging systems could be replaced by the WPT. It also improves the automation and reduces the manpower in the industries, and it has an advanced application in the electric vehicles. The proposed system in this paper is controlled using a Bluetooth module so that it can be used by any smartphones, which is energy efficient and user friendly.

3. PROPOSED METHODOLOGY

The approach used in this paper is quite simple since to avoid the programming level complexity this method compared to other planning methods it is beneficial. The method used is path select mode, which does not require more sensors in the run, which may sometimes mislead the robot to a wrong position or deviate from the track. The work has been carried out on preplanned path using code based on timing control and less sensor data processing. There are three possible position A, B, C if it is considered the robot is present anyone of the position. Assuming, it is in position A it has possibility of moving to the other two positions. Likewise, it has six possible combinations which is pre-programmed using code in the microcontroller. The schematic representation of the proposed work is shown in Figure 2.

Flowchart shown in Figure 3, explains the working of algorithm that is present for the mobile robot for path planning. The flags play a key role in the decision of the movement of the robot in the pre-planned path, since the robot has 6 possible variant paths with three destinations as the possibility. The robot moves only if the destination and position flag are different. If they are same, it does not move, and the other matter of fact is that the position flag must be updated after reaching the destination every time. The flowchart is elaborated further in the functioning of the mobile robot with relevant examples.

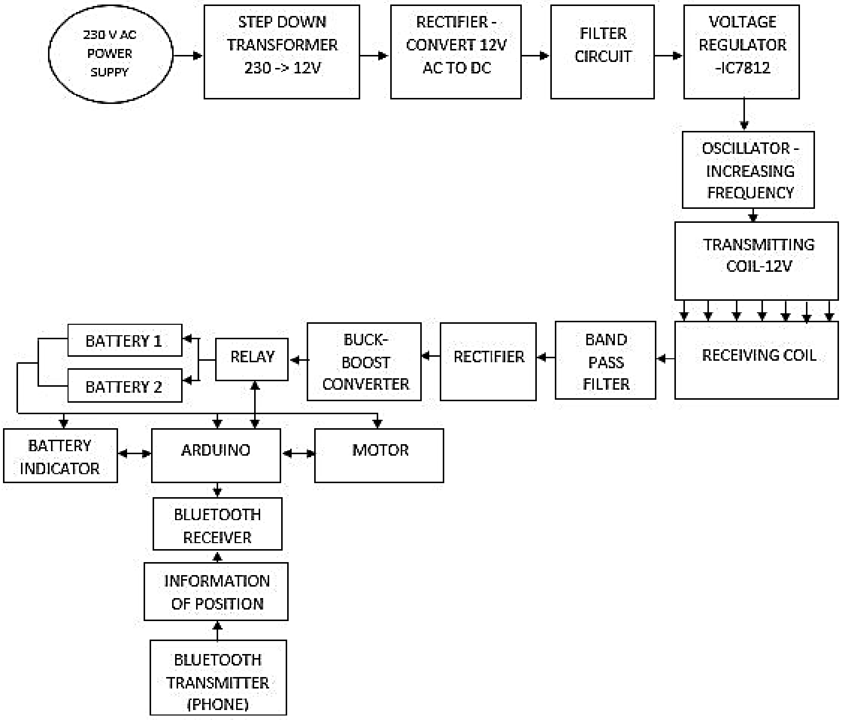

Figure 2. Proposed methodology conceptual diagram

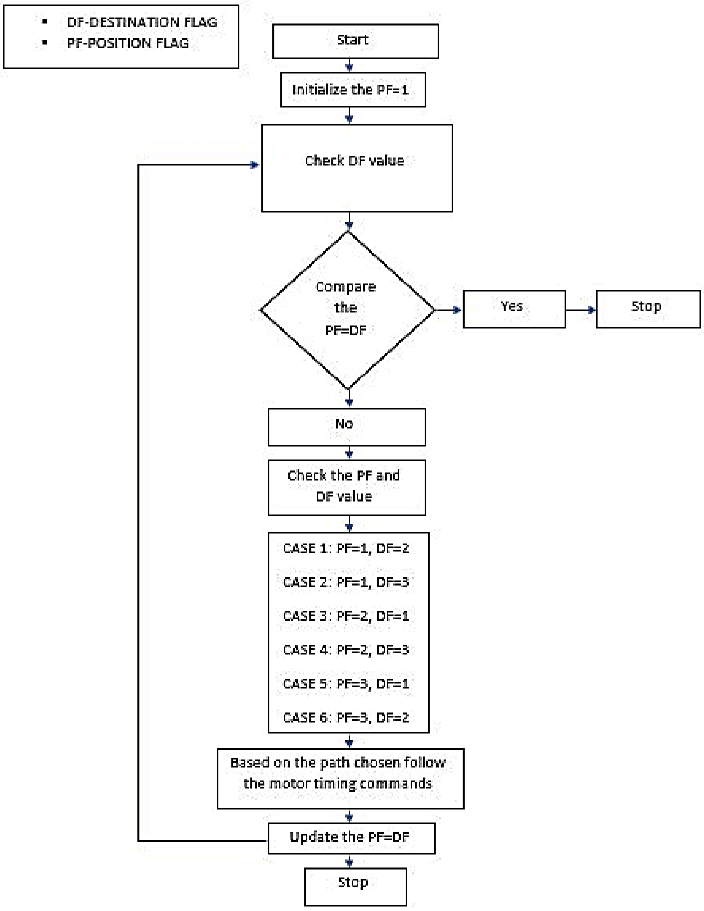

Figure 3. Flowchart of WPT with AGV

4. DESIGN OF ROBOT
4.1. Electrical design
The track is present in a T-shape to facilitate the three possible positions and each stroke of T shape is around 1 m and consists of 15 coils in each stroke of T shape. The primary coil which comprises of the primary coil is fed with a 12 V power supply which is connected in series, after stepping down from 230 V to 12 V supply. The primary coil has a diameter of 5 mm. The transmitter coils are made in such a way that after the first 7 turns is made as a center loop is taken and continue to another 7 turns and it is wound against any cylindrical object like PVC pipe. The 2N2222A transistor which has the base, input and output pins. The 2N2222A transistor's emitter is connected to the negative terminal of the input supply via it connects the mid-point of the coil, while the collector and base junction are connected to the starting end and finishing end of the primary coil.

The simple fourteen turn coil is the receiver coil, receiver coil or secondary coil is fixed at distance of maximum 5 mm from the primary coil. The distance between the coils and the efficiency are inversely proportional to each other. The output from the coil is fed to the rectifier circuit and converted DC supply is provided to charge the battery.

4.2. Design and fabrication of robot
The robot was designed, keeping in mind with shop floor situations to control the downtime as minimal as possible. The design of the robot was kept straight forward and alluring. Append and remove model was tried in this work to eliminate the presence of fasteners making the panel access easy in case of maintenance. The base of the robot is the heart of the AGV it encases all the electrical components in it. The base consists of acrylic sheet lid which is used to slid into the base of the robot. The robot comes with an adjustable induction plate and a transporter module, to carry load which has to be attached to base of the robot shown in Figures 4 and 5. Using the advanced 3-D printing technology and the source as PLA the robot has been fabricated.

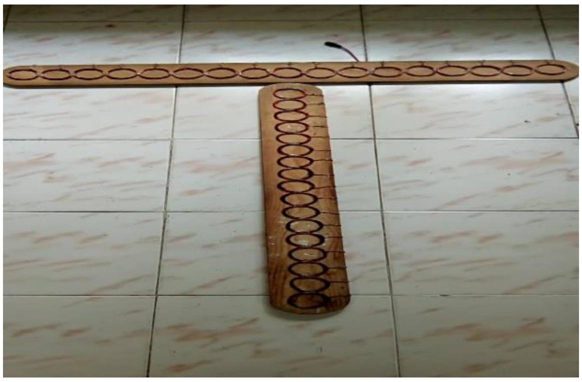

Figure 4. Front side of the track

Figure 5. Rear side of the track

4.3. Experimental setup for robot design
The main source of power is lithium-ion battery which powers the Arduino board-it serves as the controller of the robot, Bluetooth module, both motors and the motor shield, all of which are connected through a breadboard. The Arduino board inputs 4, 5, 6, 7 serve as inputs to the motor shield. The output of the motor shield is connected to the motors. Pins 6 and 7 has the control for the right motor and the pins 4 and 5 has the control for the left motor. The Arduino's (5 V) power terminal serves as source to the Bluetooth module. Pin 0 of the Arduino board is connected to the transmitter pin of the blue-tooth module and pin 1 is connected parallel to the receiver pin of the module through a resistor to reduce the voltage from 5 to 3.3 V to protect the module. The parallel combinations of the resistor help in reducing the 5 V to 3.3 V from the pin 1 and fed to the receiver end of the Bluetooth terminal.

Four receiver coil each connected to bridge rectifier are connected in parallel to yield high output current at the receiving end. The output of the parallel circuit is given to 4 V lead acid battery and to analog pin A0 in Arduino board to read the voltage. The relay which has the trigger threshold will switch from the charged battery to the power reducing battery and vice versa as the charge reduces in another. The entire set up with WPT track is shown in Figure 6.

Figure 6. Experimental setup with WPT track

5. RESULTS AND DISCUSSION

5.1. Testing of designed robot in the track

The main aim of the work is to achieve the wirelessly charging the robot and at same time navigating the robot in preloaded path based upon user's command using Bluetooth module while reducing the charging time and as well as reach the required output function as expected by the user. The primary coil receives the 12 V supply that is stepped down from the 230 V supply using step down transformer. The 12 V DC is reached by the rectifying the 12 V AC using half wave bridge rectifier and removing the ripples a filter circuit is used. Since a transistor need a DC supply these changes are made. The DC supply which is fed to the oscillator which converts the DC to AC and then given to the coil and the connection goes like this, Positive terminal of battery is sent to the mid-point of the loop, while one terminal of coil is connected to the collector of the transistor and the other is connected to the base. The emitter is connected to the negative terminal of the battery. Since the frequency must be increased, a 2N2222A transistor is used and using switching function of transistor a sine or square waveform is created and increasing the frequency it allows to transmit the power from primary to secondary.

The track consists of 15 primary coils per meter each connected to an individual 2N2222A transistor. In this work the normal frequency is been increased by switching on and off of the transistor quickly which produces a magnetic flux. The measured frequency is around 300 kHz which is sufficient to transfer the power wirelessly. The magnetic flux changes in the transmitting coil induces the magnetic induction in the receiving coil which in turn creates a small emf in the receiving end as shown in Figures 7 and 8. The emf is rectified using half wave bridge rectifier, while the emf is collected by the base plate which consists the receiver coil and it is used to charge the other battery present in the robot.

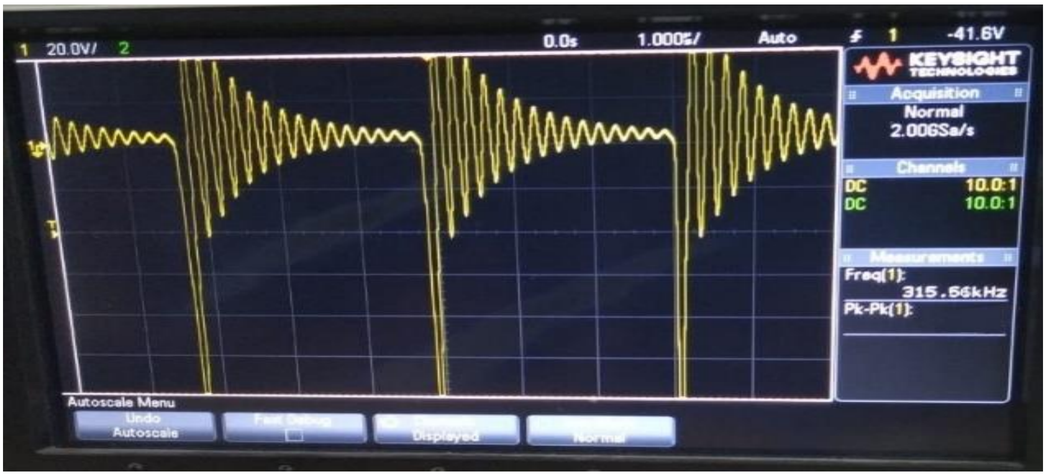

Figure 7. Waveform at the transmitting coil

Figure 8. Waveform at the receiving coil

5.2. Functioning of the mobile robot

Two batteries 8 V lithium-ion battery and a 4 V lead acid battery are used in the robot. The power to the mobile robot is driven by 8 V lithium-ion battery. The 4 V battery is used as back up battery and will be charged simultaneously. The robot is being controlled by Arduino uno. From Arduino board a HC-05 blue-tooth module is powered and used for target tracking. For the purpose of data transmission an Android phone is paired with the Bluetooth module. The mobile robot receives the destination command through the Android phone. The command signal which is received by HC-05 blue-tooth module is forwarded to Arduino board. The command signal is interpreted by Arduino board which compares the value with the current position value.

The Arduino will decide the required path to reach depending on the current place and destination to be attained. There are six possible combination of path the robot can traverse which is preloaded by the user and stored in the Arduino board. The motor command which is sent by Arduino depending on the selected path the robot moves and simultaneously battery gets charged. As the voltage drops in the main battery (8 V lithium battery) the microcontroller which detects the drop below the threshold it triggers the relay and robot is powered by the backup battery, so it allows the main battery to charge.

The major purpose of target tracking using the Path select mode is that it has lesser complications compared to other methods. Less sensor details are required to navigate the robot with the preloaded path. The mobile robot may be misled because of sensor values. There are 3 destinations, shown in Figure 9, for the mobile robot of which one will be the home position of robot. That gives the robot two possibilities to move, which makes six possible combinations as mentioned below. The final position is reached based on the user command while the robot base which has the IR sensor that reads the black color. Based on the interpretation it moves to the destination.

Figure 9. Screenshot of the mobile application that is used to control the robot

Since to avoid the complications and the risk of rising the combinations more than six it is coded in such a way that robot reaches the destination only by facing in the forward direction. For example, if the robot moves from the D1→D2 it need to come backwards initially and then take a backward turn in opposite direction to reach the destination in forward position shown in Figure 10. It has commands like reverse left and reverse right to facilitate the backward turn, while other commands are normal.

The logic behind the navigation of the robot is that it initially has a default home position. There are two flags they are the destination and the position flag. The destination flag is the command received by the user. The position flag is the current position of the robot. It's assumed that its position 1 as the home position. If the robot must reach the position 3, first the position flag will be set as 1 since it is default. Then based on the destination it changes in this case it will be updated as 3. Next the robot will select the path from 6 different ones as mentioned below. After performing the sequence of operation and reaching the destination. It updates the position flag as the destination value. And again, it follows the same steps and navigates to desired position. Below are the time-based commands that will be performed by the motor to reach the destination using the commands. The description of various commands fed is showcased in the Table 1.

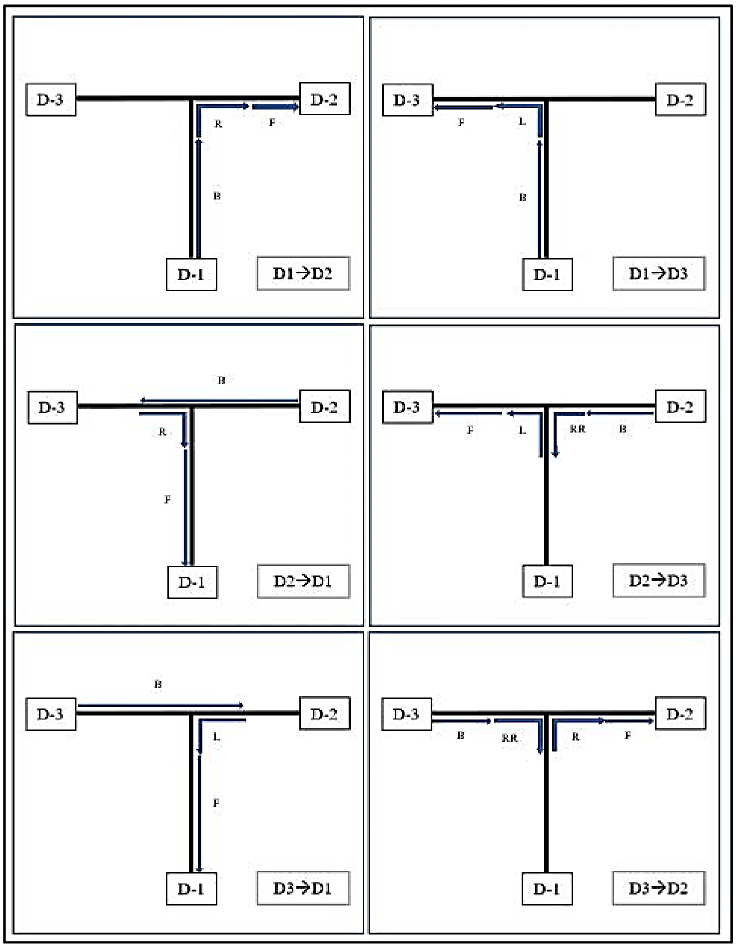

Figure 10. Image of different paths

Table 1. Description of various command

Notations	Description
F	Front
L	Left
R	Right
RL	Reverse left
RR	Reverse right
D1	Destination 1
D2	Destination 2
D3	Destination 3

6. CONCLUSION

This paper is a novel endeavor for the incorporation of two different domains like AGV and wireless power transmission. The system that was designed did not meet the desired expectations. The power transmission range is good up to a distance of 5 cm approximately. Efficiency drops with the distance between the transmitter and receiver coil increases. A single secondary coil provides an output of 2 mA which isn’t adequate to charge a battery. Hence to increase the current, the coils are made into a parallel connection. Thus, in the work it is added up with about four secondary coils to improve the output, even though the setup could reach only around 12 mA of current with voltage around 1-2.5 V. A 4 V lead acid battery takes around 20 minutes to charge the battery to 0.1 V. As a conclusion, the rate at which the battery charges are very low. The above stated is for the robot being in immobile/static condition while the robot is being in motion the charging efficiency drops even lower. Further research and advancement in the transmitter and receiver circuit is required. Use of optimizer circuit should also be researched to reduce losses, noise and to increase efficiency. The path select mode, target tracking model was completed in this paper. Path select model is more efficient to work on. Extensive programming is required for complex environments, leading to the high complexity for the programming and more data from the sensors must be collected for different or variant environments.

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