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GROUND ROBOT FOR CHARGING MULTIPLE ELECTRIC VEHICLES

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ABSTRACT

A low profile robotic system moves a Wireless Power Transfer (WPT) primary coil under a row of vehicles in a parking lot. The system positions itself underneath an Electric Vehicle (EV), adjusts the position of its primary coil to align with the receiver coil under the vehicle, and transfers a sufficient quantity of energy to charge the vehicle. Once charging is complete, the robot moves down the row of parked vehicles to charge additional vehicles.

DETAILED DESCRIPTION

The market for full electric vehicles (EVs) continues to grow very rapidly. Some jurisdictions and vehicle manufacturers plan to convert their entire fleet into full electric vehicles. Significant additions to roadside infrastructure are needed to support this changing market. In particular, a massive infrastructure build-out is needed to ensure that a sufficient number of charging stations are available for EVs.

However, installing charging stations incurs high cost, making it prohibitive for each parking spot to have permanent charge facilities. Currently, if there are more EVs that need to be charged than available charging stations, the EVs must wait until a charging station is available, which can be a great inconvenience. While self-driving cars may be able to autonomously move into parking spots with charging stations to receive charge, (and move into a normal parking space once charging is completed), this remains a problem for non-autonomous cars.

WPT is an important emerging technology for charging EVs. In this technology, a primary coil, usually embedded in the road surface, obtains energy from the power grid, and inductively couples the energy (e.g., through an air gap) to a receiver coil beneath the EV. The EV collects the transferred energy, and uses this energy to charge its batteries. The primary coils typically contain many kilograms of copper and sophisticated power electronics and therefore are expensive, making the complete deployment of a primary coil per spot in a large parking lot cost prohibitive.

Also, a limited number of today's vehicles have WPT receiver coils, which further impacts development of infrastructure. Parking structures and roadways will not install WPT infrastructure until a critical mass of vehicles can use them, and vehicle manufacturers will not offer the receiver coils until there is a critical mass of infrastructure to make them valuable.

This system transports a WPT primary coil on a low profile robot that moves underneath and between parked vehicles in a parking lot or other parking structure. It has three degrees of freedom to enable it to precisely place the primary coil in optimal alignment with the secondary coil on the underside of the EV. The robot trails a power cable behind it to connect to the power grid and enable fast charging at tens of kW power levels. *Figure 1* shows an overview of this system.

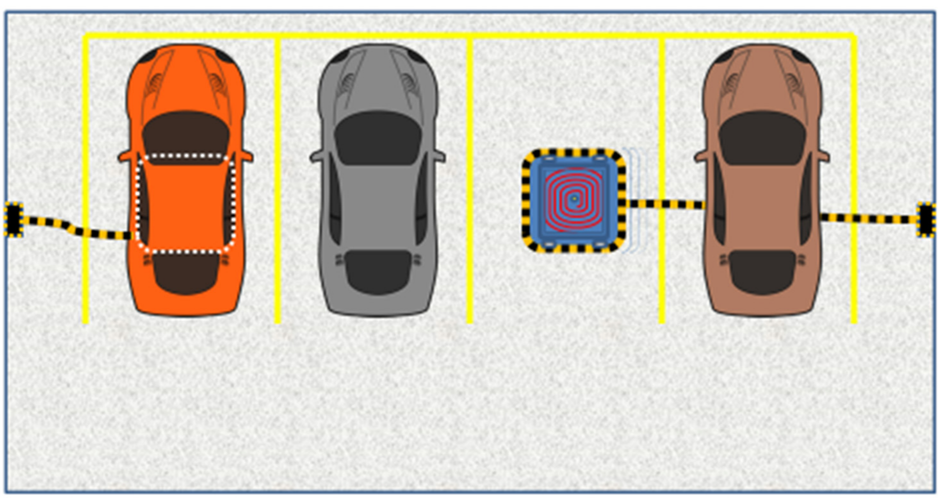

Figure 1

As shown in *Figure 1*, the robot is the square blue device, which is described in further detail below. It is capable of moving laterally between parking spots, passing underneath cars in a row between the front and rear wheels of most vehicle types. In this example, a row of four parking spots is served by two robots. However, in practical implementations, 20-100 or more charging capable spaces could be served by each robot. The left robot is underneath the red car, charging it (its position underneath is indicated by the white dotted outline). The power cable trails from a junction box on the left wall of the parking lot, through which it receives power from the grid, e.g., up to 100 kW. The right robot is visible in the unused space, and is moving to the left in the direction of the gray car, with its cable trailing underneath the brown car. Once all the cars in the row are adequately charged, the robots retract their power cables and move into a protective spot under their junction box to wait for the arrival of the next EV into their row.

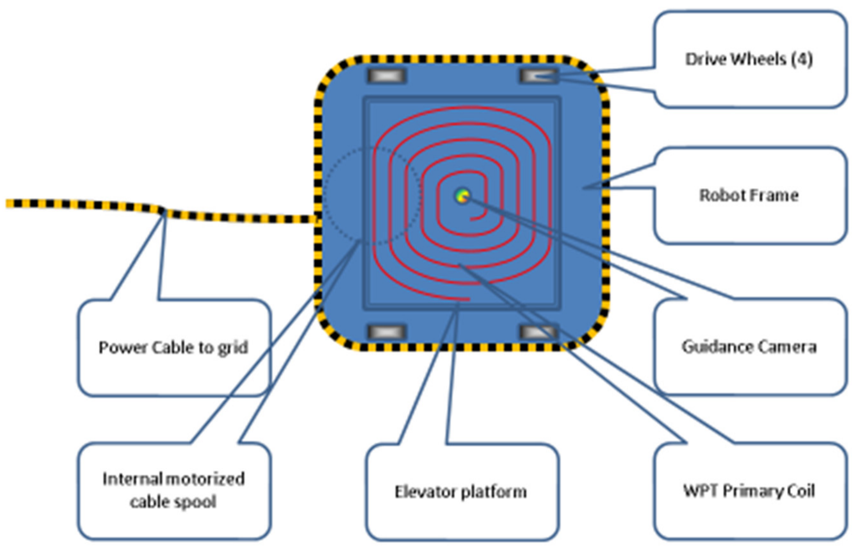

Figure 2

Figure 2 shows additional details of operation of the robot. The robot's motion system has three degrees of freedom with four drive wheels, and may move in the East/West (E/W) direction by driving the four wheels on the top and bottom edge of its frame in the same direction and speed, and can adjust its position North/South (N/S) by driving pairs of wheels at different speeds to pivot. In addition to moving N/S and E/W, the third degree of freedom is provided by an elevator platform that raises and/or lowers the WPT primary coil to maximize the coupling efficiency of the primary coil with the receiver coil in the vehicle, in some cases, forming a physical contact between the primary and receiver coils. The elevator is capable of raising the primary coil about 30 cm above the top of the robot's frame. In some cases, the robot may be about 10 cm tall when the elevator is fully retracted, and can easily pass underneath low ground clearance vehicles. The elevator may use jack screws or pantagraph mechanisms or some other mechanical component to provide controlled vertical motion of the primary coil.

Aligning the robot coil to the vehicle coil is very important to provide efficient and fast WPT. Even a small, e.g., six inch misalignment, could noticeably reduce the charging efficiency and increase the time to charge. Two ways of managing alignment issues between primary and secondary coils are presented. First, the robot may have a wide field of view guidance camera capable of viewing the underside of the vehicle, and may search for a fiducial mark, which marks the center of the receiver coil. This could be a QR code that contains vehicle ID and charging capability information, or a modulated LED that acts as a beacon. As the robot approaches the vehicle to be charged, this camera may detect the exact position of the coil, and the wheels move the robot to position the primary and receiver coils in perfect alignment.

The final capability of the robot is its ability to manage the power cable. In order to simplify the deployment, a spool of cable is stored on a motorized drum within the body of the robot. As the robot moves from the edge of the parking row towards the middle, a sensor on the spool monitors the tension on the cable, and releases or draws in the cable to maintain the tension or slack within a given range. To maximize versatility, the cable may extend more than half the length of the row in the two robot scenarios shown in *Figure 1*. Thus, if multiple EVs that need charge park on one side of the row, the robot from the other side may assist in balancing charging load. Alternatively, and to avoid pulling the power cable underneath multiple parked vehicles, a power rail may be placed in front of the vehicles, and the robot may slide along the power rail until reaching the front of the desired vehicle. The robot would then reposition itself underneath the front of the car and operate as described above. To ensure electrical safety of the cable, AC, DC or pulse power techniques may be used. In pulsed power, high voltage DC power is launched in "packets" of energy down the cable at a rate of several hundred Hz. If a packet doesn't arrive at the robot with nearly the same energy as measured at the junction box, there may be a fault in the cable and the energy flow is instantly switched off, providing a safer high power interconnect than traditional AC or DC systems.

Additionally, the cross section of the cable can be flat or trapezoidal, in order to minimize trip and snag hazards and reduce the stress on the cable as vehicles drive across it. For example, the cable may have a shallow trapezoid cross-section, which would provide a ramp that vehicles could easily drive over without damaging the cable. The cables may carry two heavy power conductors, a number of signal wires or fibers, and in some cases, liquid coolant. For example, a wire providing a power supply for 55 standard 9 ft wide parking spaces (with 480 VDC pulse power on the wire and 250 Amps of current flow) may have a voltage drop of about 13 V along the length of the cable. Due to power dissipation, liquid cooling channels may be needed to cool the primary coil and inverter electronics on the robot. Another variation for protecting the cables uses trenches with a narrow opening. The trenches can carry thick cables that unroll and roll as the robot moves forward and backward, or enclose protected high power rails on which the robot may latch onto, using conductive claws when charging. By positioning unrolled cable on the side of the parking spaces away from the driving area (for example, near the front of cars in a head-in row, or between two rows of head-to-head spaces), the probability that a car will drive over or damage the cable is minimized, and the probability that a person will walk on or trip over a cable is reduced.

Novel control system aspects include the ability to disconnect the system from a vehicle receiving charge if the vehicle starts or changes position (an indication of driving away). In this case, the system disconnects from the car and the robot retreats. Numerous safety features are implemented to assist the robot in avoiding collisions as well as features (e.g., alarms) to prevent tampering or vandalism attempts, and to ensure electrical safety of all high power electronics.

As an example embodiment, the robot's tether, primary coil, and secondary coil are high power capable and may mimic a level 3 and level 4 standard for charging, using CHAdeMO and SAE CCS high voltage DC charging (50 kW) or even power levels of other superchargers (120 kW). In this case, a typical full charge (about 50 kW·h) into an EV may take about 25 to 60 minutes. For a 120 kW power model, and assuming an office

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environment with an average 8 hour dwell time (a typical work day), a pair of robots could service a line of about (120 kW * 8 hours * 2 robots / 50 kW·h) 38 cars, for a 19:1 reduction in primary coils from the one coil per space model. In other cases where dwell time may be shorter (i.e. a shopping center), using a 2 hour dwell time and a 5 kW·h per average charge assumption with a 120 kW charge rate, the robots may spend about 2.5 minutes per EV, and could support about 96 parking spaces with a pair of robots. The ratio of robots to spaces may be optimized based upon expected use patterns, dwell times, and charge states of the parked vehicles.

In summary, the system may convert parking spaces in a large parking lot or structure capable of charging EVs without the need to equip all spaces with expensive charging stations or WPT coils. The system may charge a row of 20-100 vehicle spaces or more for the cost of about six standard charging stations, and can balance the charging capabilities across a row of cars, optimizing energy transfer based on individual needs.