Comparison of Charging Region Differences According to Receiver Structure in Drone Wireless Charging System

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***Abstract*—In the past, most of the drone was developed for military use, but recently it has been rapidly growing into industrial and civilian markets due to its potential to be applied to various fields. The industry of drones is attracting attention as a model of manufacturing and service convergence, creating synergy by converging with information technology and various services. However, the operating time of the commercial drone is limited to 15 ~ 20 minutes, so frequent wired charging is required. In order to overcome these drawbacks, this paper proposes a technology that can operate the drone by using wireless charging technology instead of cumbersome wired charging. The proposed technique can start wireless charging automatically when the drones land on the charging station. To maintain efficiency above 50%, regardless of the location of the charging station, a structure using two receiving coils has been proposed. In this case, two receiving coils can be applied to one or two receivers. In this paper, we analyze the advantages and disadvantages of these two cases and discuss the receiver structure and the method of maximizing chargeable area.**

Keywords— wireless charging system; coil; drone

I. Introduction

The definition of drones refers to unmanned aerial vehicles (UAV) that can be controlled by radio waves. It refers to aircrafts and helicopter-like UAVs that can fly or control by radio wave induction without piloting according to pre-programmed programs. A study of drones began in the 1910s, during World War I. Around 1918, a drone named 'Bug' was first developed in the United States, which is the beginning of the drones' development [1]. The earliest drones were developed for military purposes and were used as airborne missile bombing exercises, and gradually expanded to include reconnaissance and attack aircraft. In recent years, the commercial use of DHL, Amazon, Google and other global companies has increased and the value of their use in various fields is increasing [2,3,4]. The industry of drones is a key area to lead the fourth industrial revolution. The operating time of commercial drones is currently less than 15 ~ 20 minutes due to limit of battery capacity [5]. Therefore, continuous operation of the drone is impossible and frequent wired charging is required. Instead of the cumbersome wired charging method, the wireless charging technology can enable the unmanned operation of the drones. Also, a plurality of charging stations installed within the operating range of the drone can further expand the activity range of the drone.

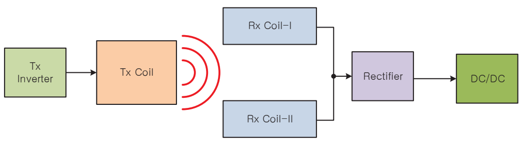
In the conventional wireless charging method, efficiency is maintained when the alignment between the transmitting and receiving coils is performed very accurately [6]. However, it is very difficult to fix the landing position of the drones at the correct position every time. Furthermore, when the size and diameter of the transmitting coil is very large relative to the receiving coil, it is very difficult to maintain a uniform charging efficiency and charging in the entire area of transmitting coil. Therefore, there is a need for a technique to maintain the chargeable efficiency regardless of the landing position in a certain area within the range of the landing error of the drones.

In this paper, we propose a method of using two receiving coils to extend the chargeable area of the drone. The proposed method has a structure in which one receiver is used by connecting the receiving coils in parallel and another method in which two receiving coils are used separately for two receivers. The advantages and disadvantages of a single receiver type and a dual receiver type are discussed.

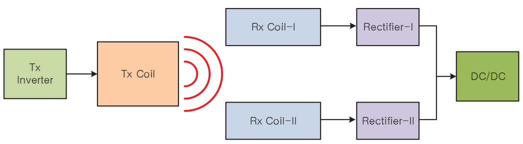
II. The Proposed Wireless Charging System

Figure 1 shows the structure of the two types of drone wireless charging systems proposed in this paper. Figure 1(a) shows the structure of the single receiver and parallel receiving coil type. The transmitter module has a full-bridge structure and controls transmission power using 0 ~ 100V variable AC / DC. The transmitting coil was a circular spiral structure with a 1 m diameter using a Litz wire. The coil spacing was varied to maximize uniform charging area. The receiver coil has a parallel structure and one receiver is used. It is designed to maintain the minimum size to reduce the weight and air resistance of the drone. The received voltage and current are sent to the transmitter using FSK (frequency-shift keying) communication and the inverter input voltage is adjusted to maintain the optimum efficiency. The system operating frequency is 140 kHz, and the maximum transmitting power is 200W and the maximum receiving power is 100W [7].

Figure 1(b) shows the structure of the dual receiving coil and dual path receiver type of wireless charging system. Figure 1(a) and Figure 1(b) use transmitting modules of the same structure. The structure of the receiver is the same as in Figure 1 (a), and the shape of the receiving coil is almost the same except for the number of turns. Table 1 shows the main parameters of transmitting and receiving coils [8].



(a) Parallel Rx coils and single receiver type



(b) Dual Rx coils and dual path receiver type

Fig. 1. Proposed structure of wireless charging system

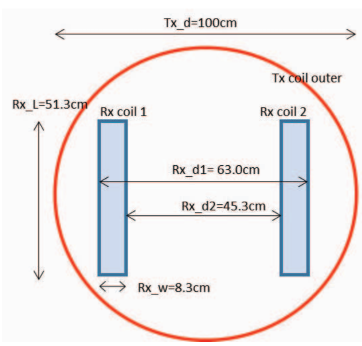


Fig. 2. Geometry of Tx and Rx Coils

Figure 2 illustrates the geometry of the transmitting (Tx) and receiving (Rx) coils. Since the size of the receiving coil is very small as compared with the transmitting coil size, it may be difficult to secure a region capable of being charged at an arbitrary position in the entire transmitting coil. Therefore, the optimized coil parameters and the shape of the transmitting coil are very important as shown in Table I. The transmitting coil has a single layer structure, and the turn interval is varied for the uniformly charged region as much as possible. The transmitting coil was installed on the ferrite and the receiving coil did not use ferrite to reduce the weight. The receiving coil is designed with minimum size to reduce air resistance and weight, and it is mounted on the lower part of the drone so that the drone can be safely landed. The receiver is mounted on the lower part of the body of the drones, and the power supply of the drones and the wireless charging are performed at the same time.

TABLE I. MAIN PARAMETERS OF TX AND RX COILS

Coils	Inductance (L) [uH]	Capacitance (C) [nF]	Quality Factor(Q)	Turn#
Tx	33.6	52.5	180.7	5
$Rx_{parallel1}$	182.7	7.1	278.8	17
$Rx_{\_parallel2}$	182.2	7.1	301.6	
$Rx_{parallel}$	91.8	14.1	328.8	
$Rx_{single1}$	99.8	13.0	263.1	13
$Rx_{\_single2}$	99.1	13.0	255.5	

$$L(Rx_{\_parrallel}) = L(Rx_{\_parrallel1}) + L(Rx_{\_parrallel2}) \quad (1)$$

Figure 3 shows the measurement setup for the wireless charging system for a drone. The battery to be charged is 6S (cells) LiPo (10,000 mAh), and can be charged within 2 hours if the maximum current is 4A. The transmitter is kept at a minimum power so that it can communicate with the receiver at any time. When the drones are landed, the Tx/Rx communication link is first connected under the condition of V_{rect} = 7V or more. When the communication is connected, the charging voltage is gradually increased, and charging starts from V_{rect} = 23V or more, and the V_{rect} voltage is controlled to be maintained between 29V and 31V (I_{max}=4.1A). When the battery voltage (V_{bat}) reaches 24.5V, charging is automatically stopped and the battery is switched to standby mode. In addition, when the battery voltage drops below 23V in standby mode, the wireless charging is restarted. All operations of the drone are controlled manually or automatically, and can be observed through the GUI (graphical user interface).

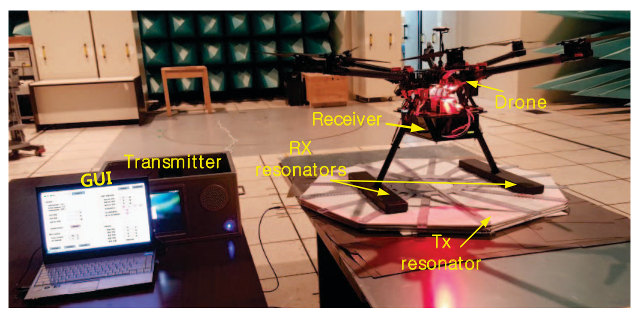
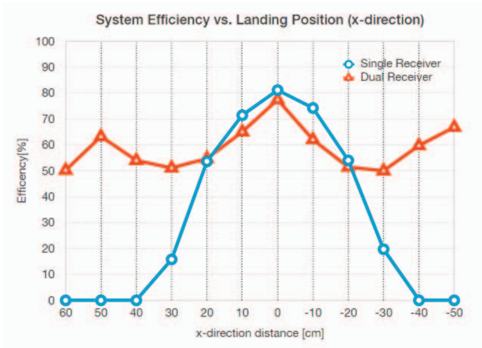


Fig. 3. Measurement setup for the wireless charging system for a drone

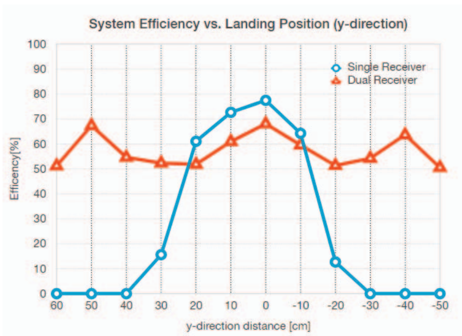
III. MEASURMENT RESULTS AND DISCUSSION

The experiment was performed at the same charging station and the case of moving in the x-axis direction and the case of moving in the y-axis direction, respectively. The receiver is divided into two types. One is a single receiver using a parallel coil and the other is two receivers using respective receiving coils.

Figure 4 shows the change of the chargeable area according to the two types of the receivers.



(a) System efficiency (x-axis direction)



(b) System efficiency (y-axis direction)

Fig. 4. System efficiency according to landing position of a drone

As shown in Figure 4, when the single receiver is used, the efficiency at the center point is somewhat higher but the chargeable area is limited compared to dual receiver type. It is disadvantageous in that the number of turns is increased and the weight is increased in order to maintain the inductance value and to secure the charging voltage.

When using a dual receiver, the rechargeable area can be expanded more than twice, so that more stable charging is possible. It can be charged even if more than 50 cm away from the center of charging station, it is possible to charge the battery within the range of the landing error of the drones with GPS (global positioning system) or visual sensors.

Generally, when the size of the transmitting coil is very large, the charging efficiency at the center of the landing station is very low, and the charging becomes impossible when the Rx coil is out of the transmitting coil. Therefore, when a single receiver type is used, if the drone moves out of the center of the landing station, charging becomes impossible or the efficiency drops sharply.

The dual path receiver structure proposed in this paper makes it possible to allow the landing error of the drones to some extent. It is possible to charge even if one of the drones is off the transmitting coil. Although the landing tolerance is about several meters when only using the GPS system, the landing tolerance can be made to be several tens of centimeters by using a vision sensor or an ultrasonic sensor.

IV. Conclusions and Future Works

In this paper, we investigate the optimum receiver structure for expanding the chargeable region when the size of the receiving coil is very small compared to the size of the transmitting coil. The dual receiver application architecture requires two receivers but can reduce the inductance of the transmitting coil. Therefore, the weight of the receiving coil can be reduced. In general, the reduction in weight is closely related to the operating time of the drones. Experimental results show that the dual receiver structure is more optimized than the single receiver structure with a wider chargeable area. The dual receiver receives the transmission power with priority in the path of better charging efficiency, so it can be charged even if it is out of the transmission coil.

Now the drones are getting smaller and smaller. So it should be prepared in case that dual receiver or dual coil can not be used. The use of a single receiving coil and receiver would be possible provided that the charging efficiency in the charging region of the charging station is uniform. EMI / EMC issues must be solved in order to receive more than 100W. One solution is to limit the output power by recognizing people nearby [9].

Acknowledgment

This work was supported by *a National Research Council of Science & Technology (NST)* grant by the Korea government [1711032848, Development of wireless E-zone and multi-dimensional energy integration technology]

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