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Original Article

Automatic Wireless Drone Charging Station Creating Essential Environment for Continuous Drone Operation

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Abstract: *With a dramatic growth in the drone market in recent years, the amount of research efforts dedicated to drones increases correspondingly. However, short battery life severely restricts applications of the unmanned aerial vehicles and has proven to be a hard issue to tackle. Among various solutions for this problem, an automatic drone charging station can be utilized. This paper proposes a fully automatic charging station which operates wirelessly. The station also allows for imprecise landing of the UAV on the platform, which is often the case for practical systems. Application of the proposed charging station may completely eliminate the need in manual battery charging of the quadrotor UAVs.*

Keywords: *Drone, Automatic Charging Station, Wireless Charging, Drone Station, Unmanned Aerial Vehicles.*

INTRODUCTION

Unmanned aerial vehicles (UAVs), also often referred to as drones, are gaining great research interest and attention as a major future technology. These vehicles have nearly unlimited potential, mainly due to their high maneuverability and miniature size, which allows their use in various applications. Among many types of UAVs, the multi-rotor UAVs with 4 rotors (quadrotors) are being used and utilized most often. Modern quadrotor applications in recent technology include disaster monitoring, 3-D mapping, surveillance, aerial photography, and unmanned cargo system. However, one of the main drawbacks of multi-rotor UAVs is their short operation time. This is due to the fact that these vehicles have to generate lift force at all times to move around, which requires high amount of electrical power. Development of new types of batteries with higher power density apart from conventional Lithium batteries may be helpful to solve this problem, but unfortunately there seems to be stagnation in this process [1]. Low battery life of conventional UAVs means that the drones need to be recharged or have their battery replaced manually every 20 or 30 minutes. This confines the drones' flight range and operation time drastically, and because of this, the drones often cannot be used to fulfill their full potential.

In recent years, a number of research works have been focused on designing new methods to solve the drone charging issue by developing automatic systems to recharge their batteries, which may eventually improve drone's practical application. The proposed solutions include laser beam systems which deliver the energy directly to the drones [2], systems that collect solar energy to support drone's long endurance flights [3], utilizing docking stations to charge the drones [4], and applying smart contact arrays [5]. However, most of these solutions have limited application range and are often impractical due to the low charging efficiency, precise positioning technology, highly complex system and other reasons. A more recent work by H. Chae proposed a wireless drone charging station to address this issue [6]. In the proposed system, the charging was performed wirelessly through a pair of two induction coils, one located at the landing pad and the other one installed on the drone. The drone identified the landing-pad, calculated the most adequate point to land and proceeded with landing process. The station minimized the error between the drone and charging coil derived from the GPS by using LED chain to assist during landing. However, this analysis requires a relatively long time, and it was proved that finding the appropriate landing point just with the LED system and land precisely was extremely difficult task. Consequently, greatly unmatched receiver coil and transmitter coil showed serious problems with the charging efficiency.

In this paper, we propose an alternative solution for the automatic drone charging station based on magnetic induction principle and distance sensing. The charging is performed wirelessly through a pair of lightweight induction coils, while receiver part is attached at the bottom of the drone and the transmitter part is positioned on the sliders moved by step motors so that it could move freely inside the station. The proposed system allows the drone to land on the platform freely, and then the station detects the UAV's position on the platform and moves the charging coil under the drone. After the charging is completed, the drone can take off and continue its operation without the need to undock. Thus, the proposed charging station is fully automatic and does not require precise drone positioning and alignment with the charging hardware after landing.

The paper proceeds as follows. System Structure describes overview of the station, wireless charging process based on magnetic induction, and operation principle. Experimental Results provides the data from each experiment.

SYSTEM STRUCTURE

Charging Station Overview:

The proposed station is composed of the following main components: aluminum frame, one ultrasonic sensor, two laser distance sensors two stepper motors and sliders moving in X and Y directions, and charging coil installed with the motors. The concept of the station is presented in Fig. 1. Aluminum frame constitutes the basis of the station with 1 mm thickness PVC panel on it for drone's landing. Two stepper motors (Jingkong/42H48 NEMA17) with sliders are arranged along X- and Y-axis with two laser sensors attached to the carriages. An ultrasonic sensor (Hanjin-Data/HDME-007) is attached at the corner of the station so that it can detect whether the drone has landed or not. Both motors are controlled by the Arduino Uno MCU, which is the main controller in the station whose task is to move the coil to the drone's location for charging process. Laser distance sensors are attached to each slider so that they can detect the drone position and help finding the center of the drone precisely. With proper algorithm, analyzing the center point of drones would be possible by utilizing distance sensors. Aluminum frame and motors are illustrated in Fig. 2.

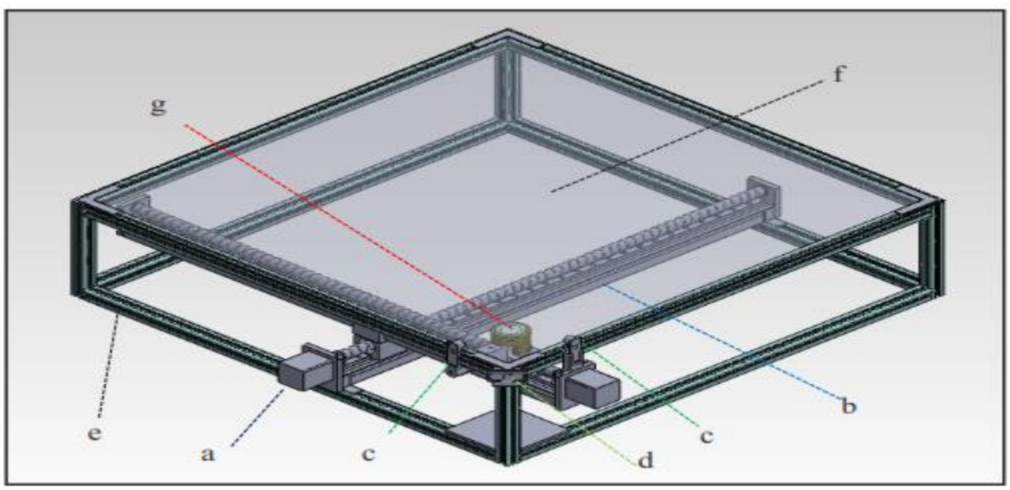

Figure 1: Overview Of The Charging Station: A) Stepper Motor, B) Slider, C) Binary Distance Laser Sensor, D) Ultrasonic Sensor, E) Aluminum Frame, F) Pvc Panel, G) Transmitter Coil

Wireless Charging:

Wireless charging technology is based on magnetic induction principle which enables electric energy transmission from one coil to another by instigating the magnetic field around the coils. The process of wireless charging based on magnetic induction begins when the transmitter transforms DC electricity into AC and generates an electromagnetic field. This field influences the receiver coil by creating a magnetic field which is eventually converted into DC electricity with the help of receiver. Unlike conventional cable charging which requires connecting wires and thus constraints both the charging station and the drone, wireless charging technology is unconstraint and thus more convenient. Moreover, any material but metal can be placed between the coils without affecting power transmission efficiency

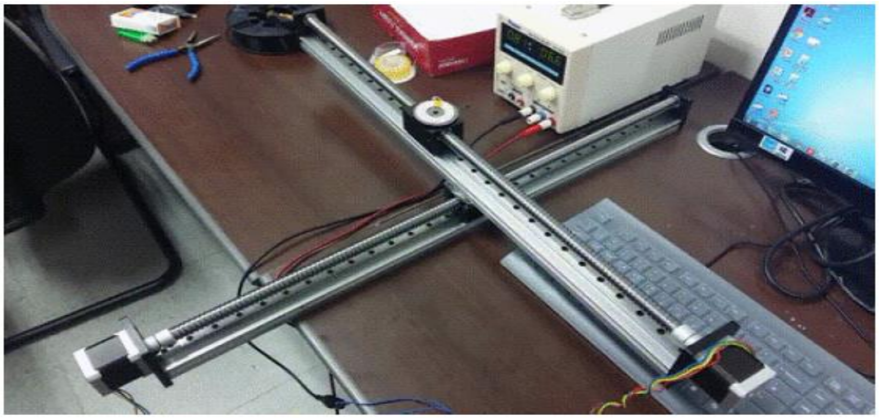

Figure 2: Stepper Motors And Sliders

In order to investigate wireless power transmission efficiency, we have conducted experiments with a pair of coils (Tenet Technetronic/TT-SEED-106990017) with the diameter of 43mm. The results are presented in Fig. 3 and Fig. 4. Fig. 3 shows the electrical currents of the transmitter and receiver coils as a function of the height gap between the two coils. Having maximal values at approximately 4 mm gap, the currents decreased dramatically after the gap exceeded 6 mm. Fig. 4 shows the electrical currents that the coils produce and receive as a function of the lateral offset between their central points. As the distance increases, the current value decreases. Since two graphs delineate the correlation between height and distance gap between two coils, adjusting two coils as precisely as possible is necessary in order to generate enough electrical efficiency to charge the drone as quickly as possible

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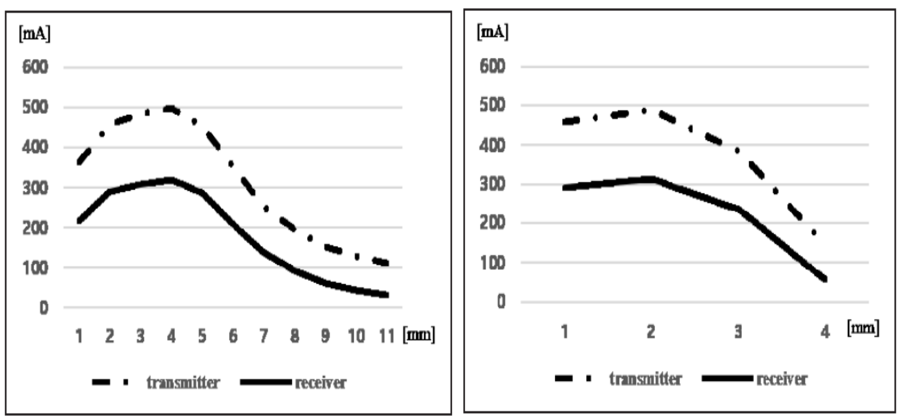

Figure 3: Electrical Currents Related To The Height & Figure 4: Electrical Currents Related To The Distance From The Central Point

Operation Principle:

The charging process is divided into three parts: Initialization, scanning, and coil positioning. During the initialization stage, the ultrasonic sensor which is placed at the corner of the station periodically scans the upper part of the panel. This stage employs just a single sensor with low electricity consumption and is therefore energy efficient. When the sensor detects the drone, an LED is switched on until the drone leaves.

If the drone is detected by the ultrasonic sensor, the system proceeds to the next step. Stepper motors operate the sliding platforms via the ball-screw mechanisms thus enabling distance measuring sensors attached at each slider to scan the position of the drone. In order to avoid using expensive laser range finder sensors, we are using simple binary lasers (Waveshare/WAV-Lasersenso), which output the value of 0 if an object is detected (which could be the legs of the drone or the receiver coil), and 1 otherwise. The maximum range that the sensors can recognize is one meter, which is less than the landing platform with the dimensions of 70x70 cm. During scanning, stepper motors operate at constant velocity according to the input voltage, which makes it easy to find positions of both lasers at which objects were detected. The first point where the distance sensor shows 0 is considered the starting point, and the central point can be calculated after the scanning is complete. Equation 1 demonstrates sample center calculation procedure:

$$x_c = \frac{x_i + x_f}{2}$$

Where x_i denotes the starting point, x_f corresponds to the last point where the object was detected, and x_c denotes the resulting central x-axis coordinate of the drone. The same procedure is performed for the other laser scanning the y-axis. After finding the central point of the drone, the control system proceeds to the last operation stage. Stepper motors move the transmitter coil to the calculated central point under the drone and the respective receiver coil which starts the charging. After the drone is charged, it can leave the station. Once the ultrasonic sensor cannot sense the drone anymore, charging cycle ends, and the transmitter coil is moved to the home position. Fig. 5 shows the operation principle of the station.

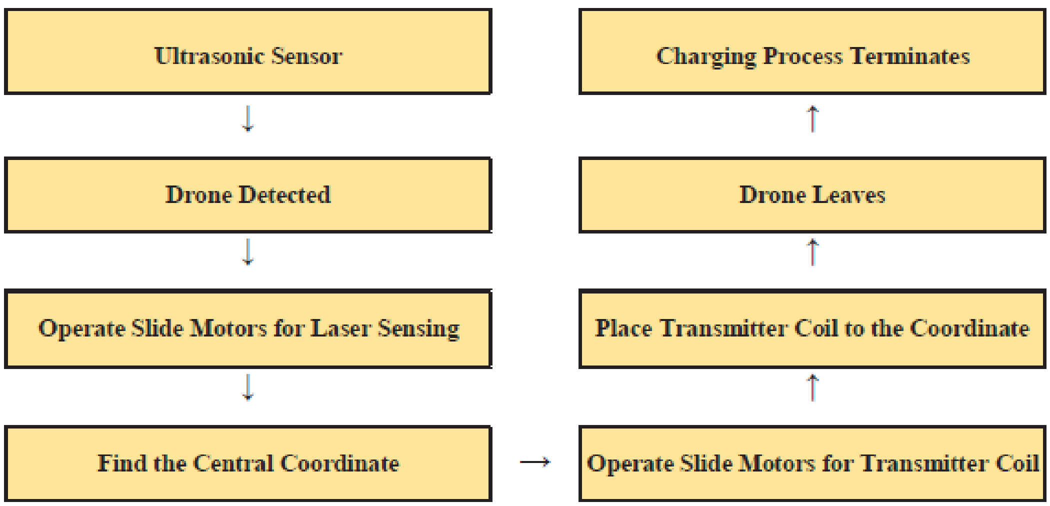

Figure 5: Flow Chart Of Charging Mechanism

EXPERIMENTAL RESULTS

In order to operate properly, the control system of the charging station should robustly and accurately detect the center of the drone after landing, irrespective of its orientation with respect to the station. In order to verify the performance of drone detection, we have designed 3 different drone orientation scenarios: when the drone faces the side of the station (and thus faces the scanning laser sensor), and when the drone is rotated by 22.5 and 45 degrees, respectively. Due to the symmetricity of the drone, all other orientation cases exceeding 45 degrees can be considered identical to the selected three. The corresponding CAD models of the drone are shown in Fig. 6.

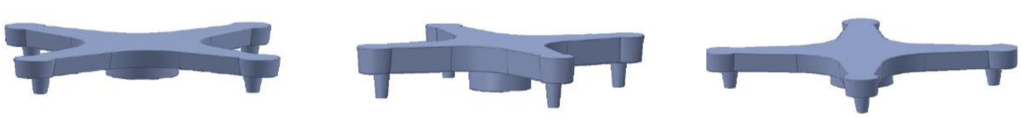

Figure 6: CAD Models Of 3 Sample Drone Positions In The Experimental Scenarios: Drone Faces The Laser Sensor (Top), The Drone Is Rotated By 22.5° (Middle) And 45° With The Sensor

The results of done scanning for each of the orientation case shown in Fig. 6 are presented in Fig. 7

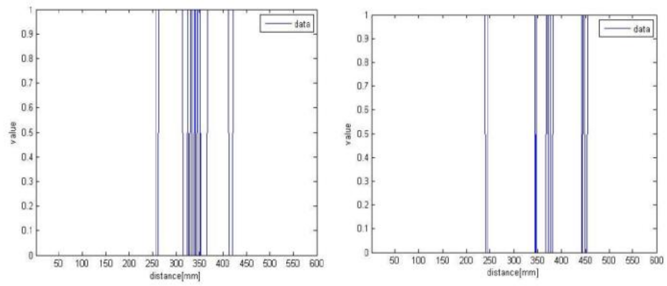

Figure 7: Sensor Data Corresponding To 3 Experimental Orientations Of The Drone

One can notice that the sensor data is quite different for the selected experimental cases. For instance, the data for zero angles (Fig. 7, top) suggests that the sensor actually detected three obstacles (left and right legs and the charging coil in the center). The first detected object was located at the distance of approximately 261 mm from the start while the last detected object was located at 423-mm distance. The x-coordinate of the central point is, therefore, 342 mm, and we can calculate the y- coordinate in the same way from the other sensor's data.In the second experimental case when the drone was rotated by approximately 22.5 degrees with respect to the side of the station (Fig. 7, middle), the sensor would detect all 4 legs and the receiver coil in the middle. In this case, the first 0-value point was detected at 245 mm while the last 0-value point was located at the distance of approximately 455 mm from the start. The x-coordinate of the central point is thus calculated to be 350 mm.

In the last experimental scenario (Fig. 7, bottom), the data indicates that the sensor detected two legs from both sides and one wider object in the middle composed of with the receiver coil and possibly 1 or both legs. The first 0-value point is at 255 mm and the last 0-value point is detected at 490 mm. The x-coordinate of the central point becomes 372.5 mm.

From the experiments, we can conclude that, however the drone lands, calculation of the central coordinate only requires the first and the last 0 value points of each distance sensor. Therefore, assuming that the drone's landing point may change every time, the calculation of the central coordinate is not affected by the drone's heading after it lands. In order to study the performance of the developed wireless charging station, we performed full charging experiments. The snapshots of the main stages of charging cycle are shown in Figure 8. The experiments demonstrated that the full process required approximately 75 minutes on average, which included sensing and charging.

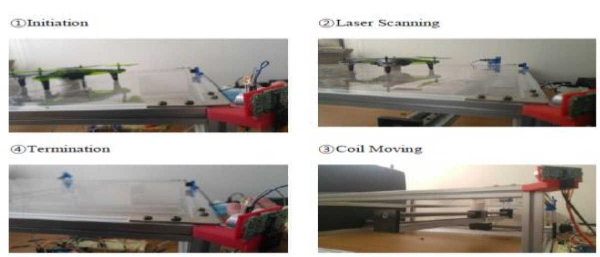

Figure 8: Different Stages Of The Charging Process: Initialization (Top-Left), Drone Scanning (Top-Right), Coil Positioning And Charging (Bottom-Right), And Termination.

CONCLUSION

Our team has finished manufacturing of a quadrotor drone Wireless Charging Station. As we primarily designed, station detects the drone with ultrasonic sensor and consequently scans it with a pair of laser sensors to determine its central coordinate. The experiments demonstrated that the accuracy of the calculation of the central coordinate of the drone was approximately 2 mm, which allowed for accurate positioning of the charging coil and efficient charging.

During the wireless charging, average electrical current provided by the receiver coil to the battery was 300 mA with voltage of 5V, which is approximately 65% of that for wire charging. The average charging time was 75 minutes in contrast to the 50 minutes required for wire charging, which we considered satisfactory for the battery which has capacity of 700 mA and requires 3.7V. There are few things that we would like to improve in the future. First of all, efficiency of charging was relatively low (65%) which negatively the practical use of the station, since the battery required more than one hour to be fully charged. With a better coil and charging circuit, we may be able to improve charging time and efficiency and thus charge the drone within an hour. Next, we are currently using a stationary power supply connected to the conventional electrical grid to provide electricity to the station. However, to use the station in remote areas, energy generators such as solar panels are necessary. Lastly, drone sensing process currently requires approximately 5 minutes which constitutes almost 7% of the total charging time. Using faster and more accurate stepper motors could reduce the required time.

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