Aerodock (a smart, autonomous charging and docking station for unmanned aerial vehicles)

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Abstract. The COVID-19 pandemic has laid bare the need for contactless operations. While unmanned aerial vehicles (UAVs) are being developed to aid humans in countless domains, the need for effective battery management and performance optimization remains a huge task. The proposed solution, the “AeroDock”, aims to tackle these challenges by using wireless power transfer (WPT) technology coupled with smart monitoring of the drone’s health. The performance and hardware checks are assessed at the user end via cloud computing and IoT technology. This system is contact-less, safe, reliable and its usage is not affected by external factors. Thus, the AeroDock is a smart docking station for UAVs which eliminates the need for human intervention in effective charging and maintenance.

Keywords: UAV, IoT, Cloud Computing, Arduino, NodeMCU, Wireless Power Transfer

1 Introduction

The recent need for contactless facilities led to a sudden bloom in the Unmanned Arial Vehicle (UAV) industry. UAVs are exciting and novel, with a lot of room for research and development [1] to make them widely accessible and a part of our society, the same way technologies like smartphones have become. One of the biggest obstacles in the path of UAVs seamlessly integrating into our society is their limited flight time and therefore, the need for human intervention at some point during their operation to ensure continuous functionality [2]. Contemporary UAVs have a flight time of 20-60 minutes, depending on their type. Moreover, security concerns and/or regulations in most countries prevent them from reaching their true potential. This paper tries to tackle the lack of smart and autonomous docking stations with support for wireless charging meant to bring UAVs one step closer to complete autonomy.

The AeroDock, as shown in ‘Figure 1’, is a completely autonomous docking station for UAVs primarily used to recharge them. It also supports a smart battery management [3] and performance optimisation system [4] that utilises the data collected by the drone to assess various parameters like battery life, optimal charging capacity, internal malfunctions and external damage.
The AeroDock utilises smart tech, IoT systems and cloud computing to increase performance tremendously compared to conventionally available docking stations. Even though the system is fully autonomous, the AeroDock provides the flexibility to change preferences based on the user’s discretion.

Fig 1. AeroDock representation

2 Literature Review

There are a huge number of possibilities, novel ideas and technologies that one may integrate into not just the charging stations, but UAVs in general. As may be expected from such a multidisciplinary field, research is being carried out in multiple domains. [1,4]

Research and development in battery technology [5] have led to higher capacities in a smaller package, all going towards helping UAVs achieve practicality. Improvement in silicon wafers and their density has allowed substantial computing power to fit inside chips smaller than the palms of human hands, making drones all the more accessible to hobbyists who can use microcomputers like the ever-popular Arduino and the Raspberry Pi [6].

The latest development in this field and the technology industry as a whole is the concept of the Internet of Things (IoT) [7-9]. The development in the field of drones and other UAVs is trying to achieve the goal of maximum possible autonomy and there are few concepts more fitting to this end than IoT. Essentially, IoT consists of several devices with internet connectivity and unique identifiers sending or receiving data over a network with minimal human involvement. This process is carried out through a secure IoT gateway, or the cloud.

The uniqueness of the AeroDock lies in its compatibility and integration with the cloud to minimise computations needed to be performed by the drone's microcomputers. The IoT gateway allows seamless monitoring and commanding of the sensorics or actuators onboard the drone.

3 Proposed Methodology

3.1 System Architecture

The AeroDock is a concatenation of three different modules as shown in ‘Figure 2’ which in itself serve specific tasks:
- **Versatile Landing Pad**: The landing area on the docking station is detected using RF ID, which eliminates the need for a camera on the UAV. Moreover, the pushrods autonomously adjust their height and hold the drone steady regardless of the dimensions of the UAV, thus making it compatible for a wide range of drones.

- **Battery Management System**: The BMS is a smart module that utilizes data collected from the drone and devices a unique and personalized charging plan for the UAV based on parameters like battery capacity, number of charging cycles, power capacity of the battery and usage time.

- **Performance Optimization Module**: This module helps diagnose any physical or electronic problems in the drone by scanning it physically and collecting error reports from the on-board microprocessor. It also analyses the data provided by the system and creates an intelligent charging plan.

![System Architecture](image1.png)

**Figure 2. System Architecture**

These three systems function simultaneously yet are not directly dependent on each other. The landing pad triggers the other two mechanisms by ensuring that the UAV is ready to be handled by the AeroDock. The BMS processes data locally to devise the charging plan and thus the charging process takes minimal time to begin. The POM utilizes cloud computing to a large extent and data analysis is done remotely while the drone is being charged. A simulated of the mechanical aberrations of the drone arms is shown in ‘Figure 3’.

![Mechanical aberrations detected using UV sensors](image2.png)

**Figure 3. Mechanical aberrations detected using UV sensors**
3.2. Structure and Schematic

- The landing pad is recognized using RF ID imprinted at its centre, directly under which the charging (transmitting) coil is placed.
- Force-sensitive resistors are used to detect when the drone has landed, following which the landing pad sinks into the docking station and the hood closes to create an enclosed area that is not affected by external interferences and uncontrollable factors like weather.
- Once the landing pad settles inside the station, two perpendicular sets of pushrods are used to align the drone at the centre of the pad. Its position is determined using IR sensors to ensure proper alignment with the coil, which then triggers the activation of the other two modules using relays.

The BMS consists of a battery health management system [10], the wireless power transfer mechanism (which uses capacitive power transfer technology [11] that provides a wide charging area, making it suitable for a multitude of drones), a microprocessor and external XT-60 connectors as a fail-safe charging mechanism.

The AeroDock has multiple charging plans based on prioritizing time or battery health [12-13]. A log of statistics such as peak battery temperature, peak power consumption, among others, is uploaded to the server for archiving purposes. Once the battery voltage reaches a satisfactory level determined by the charging plan, power flow to the charging coil stops and the drone is free to take off.

While wireless methods generally aren't as efficient as contact-based methods, they have advantages such as the lack of mechanical contacts, which may cause undesired effects like sparking and overheating [14]. A wired setup also takes away from a drone's payload capacity. Although autonomous, in the event of a malfunction, there are openings to charge the drone manually by connecting suitable wires with XT-60 connectors to it, which can be seen in ‘Figure 4’.

3.3. Practical Development

The AeroDock utilises two microcontroller units (MCU) to simultaneously process data and upload it to cloud, and receive processed data from the server. The ESP8266 provides a client-side connection to a remote server, where diagnostic analysis is performed on the data it receives from the on-board MCU of the drone.

The actuation of the push-rods and guide-rods for the landing platform is done using stepper motors controlled using stepper motor drivers for accurate positioning, as shown in ‘Figure 5’. IR sensors are used to determine the placement of the drone on the pad to ensure that maximum power transmission takes place between the transmitting and receiving coils.
Figure 5. Push rods and guide rods design
(using stepper motors for precise actuation and worm gears)

3.4. Circuit Development

The circuit governing the Aerodock involves sensors that function as both standalone and connectivity-based sensors. At the centre of the schematic is the Arduino MEGA 2560, featuring a higher I/O pin count than the Arduino UNO. It has been interfaced with the ESP8266(NodeMCU) via an I2C bus, for WI-FI connectivity. The NodeMCU transceiver module, with the aid of the Arduino, sends collected data over the IoT host platform.

The NEO-6M GPS module keeps track of the station's location and thus assisting in other computations that may require data related to the station's location such as elevation and latitude. In addition, RFID identification occurs with the aid of MFRC522 receiver, and the RFID tag is attached to the drone.

Enabling actuation of the platform is a NEMA 23 class stepper motor, integrated with the Arduino with the compact A4988 driver board. Moreover, there is a need to determine whether the battery level of the drone has crossed a satisfactory level based on the selected charging plan. To that end, a battery level indicator module on the drone communicates wirelessly with the entire system. Additionally, a pair of SR04 ultrasonic sensors ensure the silhouette of a drone, providing an additional layer of security. Once the battery voltage reaches a satisfactory level, the Arduino triggers a high-capacity relay, cutting off AC mains to the transmission coils.

Finally, the power source of all the electronics is a 15V volt LIPO battery and ensuring appropriate voltage delivery to the Arduino and the stepper motor driver are a pair of adjustable buck convertors (LM2596). All of the presented electronics and their interplay makes the Aerodock a distinct addition to the pool of innovations in the UAV world. A basic structure of the charging module has been depicted in ‘Figure 6’.

Figure 6. Basic structure of charging module
4 Results and Discussion

4.1 Circuit Realization

‘Figure 7’ is a broad overview of the circuit layout which is a reference for building the actual circuit. Most sensors are powered by the Arduino Mega using its 5V supply and ground terminals. All sensors are digital in nature, and multiple sensors can be interfaced with the Arduino Mega utilising the I2C bus. For example, the ESP8266 Wi-Fi module communicates with the Arduino to send across data such as battery level, GPS statistics and more to a cloud platform, the one being used in this case being Thingspeak.

The aim of this article was to introduce a solution for UAV maintenance that is highly scalable and relatively inexpensive. To that end, the Arduino and the NodeMCU are the perfect duo to enable IoT operations. In this highly progressive era, open-source tech leads the way in innovation and accessibility. Both Arduino and NodeMCU are software and hardware development environments based on open-source philosophy and come on inexpensive SoCs (System on Chip).

![Figure 7. Overview of the circuit layout](image)

4.2 Thingspeak interfacing:

- Thingspeak is an IoT analytics platform used to visualise, manipulate and work with sensor data.
- It is required to sign up and create various channels for each of our sensors.
- Each channel we create must have a unique read/write API key. This allows the AeroDock to connect with Thingspeak over the internet and allows access regardless of the operator's location.
- There is scope for customising and adding widgets to the platform for a clear idea of the data.
- Data is stored, analysed and computed upon, relaying targeted on-demand information to the user.
4.3 Model Representation

In practice, ‘Figure 8’ shows what the system will look like. The drone being used for representation purposes closely resembles the S550. The AeroDock consists of a containment out of which the inductive platform would rise with aid of a rack and pinion mechanism actuated using an appropriate stepper motor. The charging circuit, coupled with a relay, receives power from the AC mains supply, while the electronics are powered using the LIPO.

Figure 8. Model developed for representation and simulation

Figure 9. Our test model for the platform of the AeroDock

Figure 10. Battery management System being concatenated with the landing area

‘Figure 9’ and ‘Figure 10’ shows the prototype of our model in action. It shows a drone stand prototype attached with connection rings placed at the dock. The metal rings attached to both the stand serve the purpose of bridging the connection gap between the power source and the battery. The NodeMCU is connected to the Arduino such that to maintain a constant serial communication between them. As a result of this communication all the various components can also be controlled manually from the user application as an additional feature. A simple voltage comparator circuit built using LM311 acts as a comparison between the required reference voltage and the battery voltage to prevent overcharging of the battery.
5 Conclusion

After analysing and exploring the development of the AeroDock, it is seen that this device has the ability to autonomously charge the UAV efficiently, and also diagnose mechanical and electronic errors within the system. The reports generated by it are made directly accessible to the user. This device is smart because it delivers personalized services for each drone, while also helping the user increase the drone’s performance.

5.1 Future Scope

The AeroDock, although complete in itself, is destined for betterment in the future because of its ability to integrate with IoT services and the world wide web (WWW). The product is self-sufficient in a way that it is able to determine the most suitable plans for performing the tasks assigned to it, while it also gives the user a multitude of choices to meet their personal needs in terms of time management, productivity and longevity.

The ability of the AeroDock to communicate over the internet gives us the opportunity to utilize the resources of the world wide web and provide a one stop destination to the users in the form of a web application. The application would be used to closely monitor the performance of the AeroDock while simultaneously helping us provide many more remotely accessible features.

We wish to integrate all the AeroDocks into one common network that would increase the utility of this device. This would help us device route maps and plan charging periods with the flexibility to decide the charging and diagnosis hotspots for the UAV in question [16]. Furthermore, it would also act as rescue stations for UAVs in flight that are able to report anomalies or accidents.

With the course of time, the AeroDock will prove to be an important resource in the growth of the unmanned aerial vehicle industry. With its smart features and advanced technology, the device will help boost the ongoing research in this field by providing a new perspective that concatenates pre-existing and newly developed solutions.

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