Battery Autonomous Transfer Module for Aerial Networks

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The increasing adoption of Unmanned Aerial Systems and Unmanned Aerial Vehicles across various industries has created a growing demand for efficient drone charging solutions to ensure uninterrupted mission operations. This paper presents the Battery Autonomous Transfer Module for Aerial Networks; a project focused on exploring the feasibility of autonomous drone battery-swapping technology as a solution to this challenge. The proposed system is designed to autonomously remove a depleted battery from a small drone, replace it with a fully charged battery, and initiate recharging of the removed battery — all within a timeframe comparable to manual battery replacement. The prototype leverages microcontrollers, off-the-shelf components, and additive manufacturing techniques to achieve automation. System performance is evaluated based on key metrics such as swap time, success rate, and operational reliability. This study aims to demonstrate the potential of an autonomous battery swapping system as a viable solution to enhance drone mission efficiency and reduce downtime.

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I. Introduction

THE past decades have seen a surge of interest in using UAS (Unmanned Aerial Systems) and UAVs (Unmanned Aerial Vehicles) in various applications including delivery drones and military drones. Companies such as Amazon and Walmart have expressed great interest in the use of drones in a last-mile delivery capacity. Likewise, drones have seen a surge in use in the militaries of the world. The U.S. military has seen an increased use of drones since the global war on terror and the recent war in Ukraine has seen militaries of the world panic to develop drone systems for both offensive and defensive roles. While demonstrably useful tools, these drones have multiple drawbacks. One major drawback of drones over previously used aircraft are their short mission lifespans due to battery limitations. Current drone operation times are measured in minutes, while many missions may require the use of the drone for multiple hours. Such operations must currently be served by larger, traditionally powered aircraft, a larger number of drones, or completed in phases. This project aims to design and evaluate a system to provide quicker turnaround times for current UAS and UAVs without requiring major modifications of current airframes or batteries called BATMAN (Battery Autonomous Transfer Module for Aerial Networks). The specific focus of the system is on networks of drones that require frequent battery swaps beyond what a human operator could be considered to reliably perform. This system aims to completely swap a battery from a drone and redeploy the drone within a similar time frame a human operator can achieve. Previous work in this field has seen the creation of similar systems; however, they require modification to the airframe or bespoke airframes all together [1] . This project aims to present a solution to autonomous battery swapping that does not require expensive hardware or large startup costs. Due to the nature of this project as an undergraduate research project, the goal of a simple prototype is presented. The authors note that, due to time limitations, an in-depth analysis of the system was deemed out of the scope of this project. Simple design and initial construction are the major goals this project seeks to achieve.

II. Methodology

This project did not initially have a specific commercially available drone selected for use, as the platform is meant to be airframe agnostic in its final inception; however, a six-rotor drone of similar size to those produced by industry leaders, such as DJI and Parrot was chosen. This drone chassis was chosen for this project due to its similarities with drones used in industry such as physical dimensions and battery specifications. This drone was readily available within the department, provided by one of the faculty members for use within the project. The drone is approximately 60 inches in diameter, and around 28 inches tall. The drone uses a 6700mAhr battery about 13.7 in long, 4.5 in wide, and 4.8 in tall.

Fig. 1 Drone Chassis Used in Development

Due to the nature of this project, sophisticated analysis is left for future work. The methodology for the construction and design of the system being studied in this paper is outlined below. Particular emphasis was placed on easy construction and the lowest possible cost when designing the system. Some other characteristics focused on were 1) expandability; 2) compatibility with other airframes; 3) networking with other systems; 4) drone size constraints; and 5) swap completion time and success rate.

A. System design

The BATMAN system consists of three main components: 1) a docking platform seen in Fig. 2; 2) a battery case; and 3) the swapping mechanism. The docking platform houses the rest of the components of the system and serves as a physical base for all other systems. Also embedded in the docking platform is the charging circuitry, a conveyor belt to assist in battery removal and swapping, as well as power for the rest of the system. The method for charging chosen was wireless induction. This was chosen to reduce the complexity of the system by avoiding having to make physical connection with the battery once removed from the drone body. Previous research shows that charging LiPo (Lithium Polymer) batteries through wireless induction charging is possible [3] . This project aims to follow their charging scheme; however, the use of off-the-shelf wireless charging coils was made to reduce manufacturing time and costs. Given the tolerance possible for the coil spacing for inductive charging of LiPo batteries presented in Ref. 3 the battery should be capable of charging through the conveyor belt system.

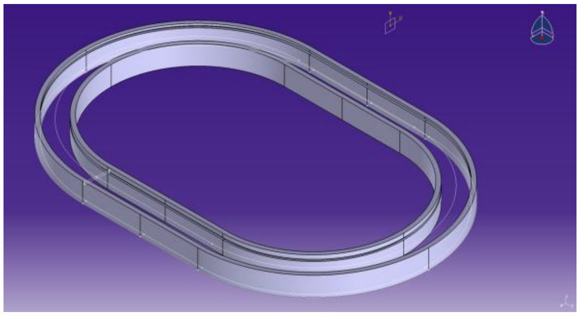

Fig. 2 Railing Subsection of Conveyor Belt

While this project aims to maintain most original components on the drone being tested, an aftermarket battery case, seen in Fig. 3, was determined to be required to remove and reattach the battery without input from a human operator. The battery case was designed to fit the original battery used by the drone in question and can be modified in future to fit all similarly shaped and sized drone batteries in the future. The case locks into the drone chassis with electromagnetically locking spring-loaded pins. These pins can be controlled from the charging platform directly once the drone is detected to be in place and will draw power from the drone battery directly. The battery case also houses one component of the charging system. The induction charging system used by BATMAN requires two coils, one connected physically to the battery. This second coil is embedded in the very bottom of the battery case to ensure that it is as close as possible to the powered coil embedded in the conveyor belt. Careful consideration has been made to design the case in a manner in which the coils are not too far away for charging to occur. Because the battery case is carried by the drone during flight, considerations on weight have been made. For the specific drone in use for this project, weight is not a major concern; however, in applications of BATMAN in the field, weight will likely be a major concern.

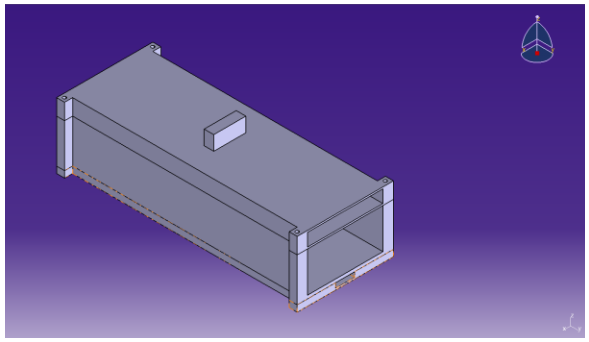

Fig. 3 Battery Case

Creating a system that can remove the battery from the drone easily while maintaining a solid mounting point for the battery while in flight provided a challenge to the authors of the paper and multiple subsystems were investigated. Initially, systems used on electric cars were investigated, however, they were deemed to not be practical for the requirements of this project [6] . Another design that was considered was a rotating spit design. This design involved batteries mounted on a rotating gatling gun style mount, with multiple charged batteries ready to swap into the drone at any given time. When the drone landed the depleted battery would be rotated out and swapped in with a fresh one. This design was also deemed too complex for the timeframe given to design this system.

The final battery swap design is a conveyor system in which the battery is removed through an electromagnetic locking mechanism and then pushed out of the way by a conveyor belt. Once the depleted battery is removed it is manipulated over the wireless charging station, where the battery is able to charge through the conveyor belt using the previously mentioned inductive charging method.

B. Controls

The system is to be controlled via microcontrollers. All the electronics chosen for the project are readily available off the shelf electronics, such as stepper motors and servos. Some components such as the electromagnets used for the locking pin system are repurposed from other uses, in the case of the magnets, they are taken from an electronically locking door. These components are undergoing minor modifications to allow them to be used in tandem with off-the-shelf microcontrollers.

Due to the low computing requirements of the controls system, Arduinos were chosen to be the main control units for the system. Multiple Arduinos will be used in parallel to control different systems together. These microcontrollers are able to interface with the other hardware used, such as the stepper motors used in the conveyor belt, either directly or through intermediary electronic control components such as motor controllers. Specialized and bespoke electronics were avoided in the design process to avoid unneeded complexity and cost.

III. Discussion

The final system design involves seven major steps: 1) docking, 2) battery removal, 3) positioning of a new battery, 4) attaching the new battery, 5) drone takeoff, 6) positioning of the old battery, and 7) finally charging of the old battery. The specifics of each step are outlined below:

1. Docking
    a. The drone lands on the platform and the battery are aligned with the removal mechanism. The landing is envisioned to be automated, however, this is outside the scope of this project to design and analyze.
2. Battery Removal
    a. The battery locking pins are released and the battery is allowed to separate from the drone chassis. The battery is completely supported by the conveyor belt at this point and is free of constraints from the drone itself, including all cable connections.
3. Positioning of the new battery
    a. Due to the way the batteries are both situated on the conveyor belt the removal of the old battery from the vicinity of the drone and the positioning of the new battery are done simultaneously,

with the positioning of the new battery and old batteries in the correct places for their later steps planned out correctly it is possible to always have both lined up at the end of the this step.

4. Attaching the new battery
   a. The new battery is now in the correct position to be attached to the drone. The locking pins are engaged, and the cable is connected to the drone allowing power transfer. The drone is now powered and ready to continue in its mission.
5. Takeoff
   a. The drone is cleared of all obstructions possibly present and is allowed to take off.
6. Positioning of the old battery
   a. The old battery should in theory already be in the correct position at this point, but checks are completed through sensors to ensure this is the case, and if the battery is not in the correct position its position is corrected through the conveyor belt.
7. Charging of the old battery
   a. The old battery is allowed to charge to capacity through the induction coils.

All systems to ensure this process can be finished successfully have been designed and initial construction has been completed by the members of the team. However, due to time constraints, testing and validation of various aspects of the design have not been completed, neither has the creation of the control software for the system. The focus of the analysis for the feasibility of further development, and future deployment of this system has been the mechanics of it. Software controls are left to the later stages of development, which at this point is yet to be completed.

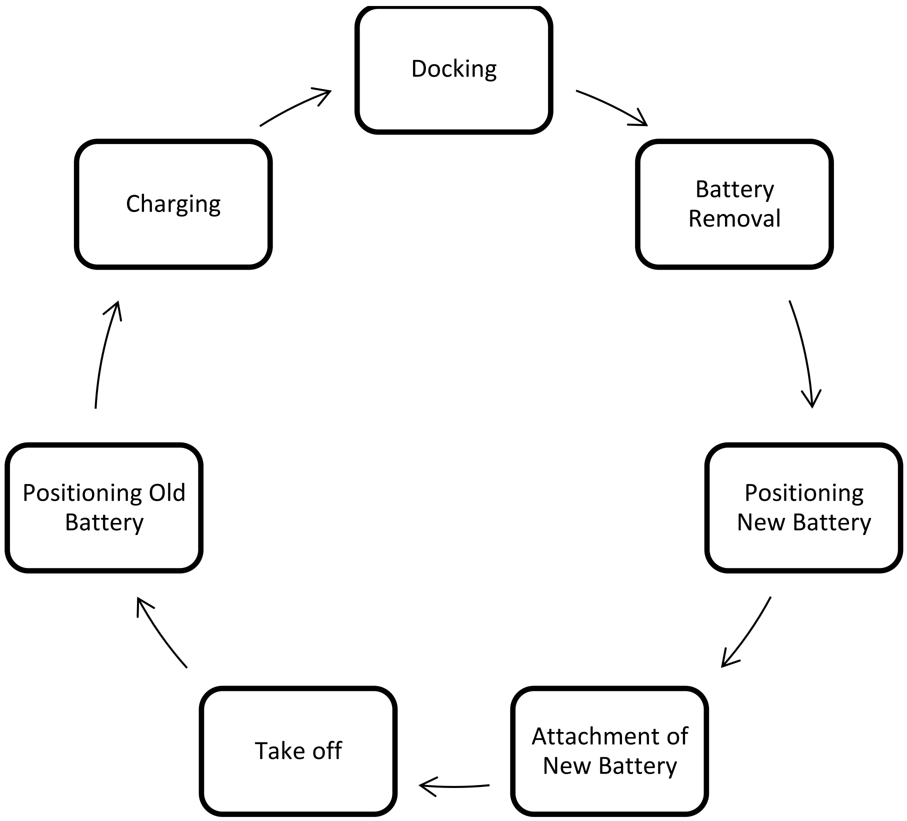

Fig. 4 Process Diagram

IV. Conclusion

The growing reliance on UAS and UAVs for both commercial and military applications highlight the urgent need to address their operational limitations, particularly the short mission lifespans caused by battery constraints. Although, this project was not able to conduct any robust testing and analysis of the BATMAN battery swapping system, it is the belief of the authors of this paper that this system demonstrates the future of battery swapping technology which eliminates the need for costly modifications to existing airframes in the field of UAS and UAV networks. Further testing and analysis of BATMAN is needed to support the use of this exact system in the field, however, even if the specific designs outlined in this paper are not successful, the concept battery swapping, its applications, and its construction lay a strong foundation for future advancements in autonomous drone networks and shows promise as noted in this paper.

The authors of this paper would like to continue the development of this design and refinement of the concept in the future. Weight reduction of the battery case, as well as a redesign of the charging system, is likely to be the focus of near future work post completion and testing of the current design.

Acknowledgments

The authors of this paper would like to highlight the support of the Department of Aerospace Engineering in Bagley College of Engineering at Mississippi State University for financial support vital in the completion of this project. The support of Calvin R. Walker and Brandon Lasseigne are also acknowledged for their roles as primary advisors. It is also important to note the guidance and help of Robert Wolz.

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