DESIGN, MODELLING AND FABRICATION OF CONTROL SYSTEM FOR RAM AIR PARACHUTE

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Introduction:

In the modern world, efficient and reliable cargo delivery systems are crucial, especially in remote or hard-to-reach areas. Traditional methods often face significant challenges such as high costs, logistical constraints, and safety concerns. This project aims to address these challenges by designing an autonomous control system for a cargo-delivering paraglider. The system leverages advanced technology and aviation principles to ensure safer, cost-effective, and versatile cargo delivery solutions. This innovation is particularly beneficial for applications in disaster relief, environmental monitoring, agriculture, and search and rescue operations. By integrating sensors, sophisticated control algorithms, and robust hardware, this project seeks to contribute to the evolution of autonomous aerial systems, promoting efficiency and accessibility in logistics and remote operations.

Background Study:

The study examines the relative motion between the parafoil canopy and payload in the experimental vehicle ALEX, focusing on the flexible textile linkage between the parafoil and load. The study characterizes different types of relative motions and their impact on the vehicle's flight qualities. A sensor system is designed to record relative motion during flight tests, and flight data is acquired using a customized video-measurement system and image processing algorithms. The parafoil-load system is modelled in a computer simulation environment, and parameters are estimated and validated using additional flight test data. These computer models are used for simulation studies to analyse the effects of relative motion, providing measurement improvements and deeper insights into flight mechanics.

- **Strickert, Gordon. "Study on the relative motion of parafoil-load-systems." Aerospace Science and Technology 8.6 (2004): 479-488.**

Furthermore, the aerodynamic performance of ram-air parachutes is examined through computational fluid dynamics (CFD) simulations and experimental validation, focusing on lift curve slopes, surface pressure, and velocity fields around the canopy. This research also addresses the limitations of numerical investigations in predicting free flight behaviour compared to wind tunnel tests, highlighting the need for further studies to bridge the gap between numerical predictions and actual field performance.

- **Zurita, Christian A. Guzman, "Preliminary Test Predictions for Scale Ram-Air Parachute Testing" (2019).**

Lastly, a dynamic model for a parafoil and payload aircraft, including a 9-degree-of-freedom representation, is developed to capture control responses accurately. This comprehensive background sets the stage for the project's innovative approach to autonomous cargo delivery using a paraglider system.

- **Slegers, N., and Costello, M., "Comparison of Measured and Simulated Motion of a Controllable Parafoil and Payload System," AIAA Atmospheric Flight Mechanics Conference and Exhibit, Austin, Texas, August 2003**

Objectives:

The overall aim of our project appears to be to develop and demonstrate a functional control system for a Ram-Air Parachute. This involves designing, modelling, and fabricating the control system with the intention of showcasing its effectiveness and feasibility. The overarching goal is likely to contribute to advancements in parachute technology, particularly in terms of control, manoeuvrability and testing for machine learning and autonomy.

The objective of our project will be to demonstrate the following points:

- Designing a control system for Ram-Air Parachute.
- Modelling the control system for Ram-Air Parachute.
- Fabricating the control system for Ram-Air Parachute.

Methodology:

1. PLA (Polylactic Acid) for Capsule Material: The capsule that houses the payload is constructed using PLA, a biodegradable thermoplastic derived from renewable resources. The capsule is 3D printed to ensure precision and durability.

2. Ripstop Nylon for Parachute Material: The parachute is made from ripstop nylon, a lightweight and durable fabric known for its resistance to tearing and ripping. This material is crucial for ensuring the parachute's longevity and reliability during multiple deployments.

Methods:

1. Design and Fabrication of the Capsule:

- The capsule is designed using CAD software, ensuring it meets the specific requirements for housing and protecting the payload.
- The design is then 3D printed using PLA, allowing for rapid prototyping and easy modifications.
- After printing, the capsule undergoes a series of virtual tests to ensure it can withstand the forces experienced during flight and landing.

2. Construction of the Parachute:

- The parachute is designed to maximize aerodynamic efficiency and stability. Ripstop nylon is cut and sewn into the desired shape, ensuring all seams are reinforced to prevent tearing.
- The parachute is attached to the capsule using a flexible textile linkage, which allows for some relative motion between the canopy and the payload, enhancing stability.

3. Integration of Sensors and Control Systems:

- A sensor system is integrated into the capsule to monitor relative motion between the parafoil and the payload. This system includes accelerometers, gyroscopes, and GPS modules.
- Data from these sensors are recorded and analysed using machine learning algorithms to improve the control system's accuracy and responsiveness.
- The control system includes actuators that adjust the parafoil's brakes and canopy tilt to control the flight path and ensure precise landing.

4. Simulation and Modelling:

- The parafoil-load system is modelled in a computer simulation environment. This involves creating a dynamic model that accurately represents the control response of the aircraft.
- Parameters for the simulation are estimated and validated using machine learning techniques, ensuring the model's accuracy.
- The simulation studies analyse the effects of relative motion between the parafoil and the payload, providing deeper insights into flight mechanics and potential improvements in design.

Work Details:

1. Simulation Testing:

- The autonomous cargo-delivering paraglider undergoes a series of computer simulations to gather data and validate the design. These simulations replicate various environmental conditions to ensure the system's robustness and reliability.
- During these simulations, the sensor system records data on the relative motion between the parafoil and the payload, which is then analysed using machine learning algorithms to refine the control algorithms

2. Data Analysis:

- Simulation data is processed using machine learning techniques to extract meaningful information about the flight dynamics.
- This data is compared with the simulation results to identify discrepancies and areas for improvement.

3. Iteration and Improvement:

- Based on the analysis, design modifications are made to the capsule, parachute, and control system to enhance performance.
- The improved designs are then subjected to further simulation testing and analysis, creating a continuous cycle of refinement.

4. Validation and Application:

- The final design is validated through extensive simulation and machine learning analysis, ensuring it meets the project's goals of efficient, reliable, and autonomous cargo delivery.

- Potential applications in disaster relief, environmental monitoring, agriculture, and search and rescue operations are explored, demonstrating the system's versatility and effectiveness.

Results and Conclusions:

The simulation of the ram-air parachute within a controlled 1000m x 1000m x 1000m environment with variable air velocities yielded results consistent with our expectations. Different altitude ranges were simulated, each affecting the parachute's descent path in response to varying horizontal and vertical wind speeds.

Specifically, at altitudes between 850m and 1000m, the parachute exhibited significant forward speed and moderate lateral movement, with horizontal velocities of 40 meters per second in the x-direction and 10 meters per second in the y-direction. As altitude decreased to between 600m and 850m, forward speed decreased to 5 meters per second while lateral speed increased to 20 meters per second. At lower altitudes of 400m to 600m, horizontal movement ceased, and the descent primarily consisted of vertical downward movement at 20 meters per second in the y-direction.

At the lowest altitude range, from sea level to 400m, horizontal velocity reduced to 5 meters per second in the x-direction, accompanied by a vertical descent of 1 meter per second in the z-direction. These simulations effectively demonstrated how varying air velocities at different altitudes influence the parachute's trajectory and behaviour under real-world conditions.

The parachute maintained stable velocities in all directions after an initial spike exceeding 30 m/s due to adverse wind conditions at deployment. This initial instability underscores the need for improved wind resistance and control mechanisms during deployment to ensure consistent performance.

While roll, pitch, and yaw characteristics were generally satisfactory, smoother transitions and turns are required. Integration of machine learning algorithms holds promise for optimizing real-time control adjustments, thereby improving manoeuvre fluidity and precision. Future efforts will focus on developing and testing these algorithms to enhance control and stability across all flight phases.

Oscillations along the x-axis at 162 seconds indicate a need for damping mechanisms to stabilize performance during flight. Future developments will prioritize the implementation of gradual control commands to ensure smoother transitions and enhance overall safety and performance during flight operations.

Description of the innovation in the project:

- Autonomous Control System: Developed for a ram-air parachute, the project features an advanced autonomous control system integrating sensors, algorithms, and robust hardware to operate independently during cargo deliveries.
- Adaptive Flight Dynamics: The parachute dynamically adjusts to real-time conditions like varying wind speeds and altitudes, ensuring stable and efficient descent paths.
- Machine Learning Integration: Utilizes machine learning algorithms to analyse flight data, enhancing real-time decision-making and optimizing control strategies for improved stability and manoeuvrability.
- Aerodynamic Optimization: Computational fluid dynamics (CFD) simulations optimize aerodynamic design, enhancing lift and drag efficiency to maximize payload capacity and endurance.
- Versatile Applications: Designed for diverse applications such as disaster relief, environmental monitoring, agriculture, and search and rescue operations, offering scalable solutions for challenging logistics.

These innovations represent a significant leap forward in autonomous aerial systems, promising safer, more cost-effective, and reliable cargo delivery in remote and inaccessible areas.

Future work scope:

The project on designing, modelling, and fabricating a ram-air parachute control system has achieved significant milestones in manual operation capabilities and simulation validation. A robust manual control system enables precise manipulation of the canopy's angle of attack and roll, ensuring reliable performance under various conditions. Extensive simulations have validated the system's aerodynamic performance, structural integrity, and responsiveness, laying a strong foundation for real-time testing. Field tests will validate its reliability, safety, and operational effectiveness, gathering essential user feedback.

Future work involves optimizing electronic components for enhanced reliability and efficiency, focusing on sensor integration, power management, and redundancy systems. Integration of machine learning algorithms holds promise for autonomous operations, leveraging adaptive decision-making capabilities to enhance safety and efficiency. This advancement requires rigorous data collection, algorithm refinement, and iterative testing to achieve fully autonomous parachute systems.

In conclusion, while significant progress has been made in manual operations and simulation validation, upcoming phases will focus on real-world testing and optimization to meet operational needs and pioneer advancements in aerial mobility and safety.