Model-based Design Development and Control of a Wind Resistant Multirotor UAV

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Abstract

With applications towards search and rescue missions, the main objective of this thesis work is to provide a suitable multirotor UAV design. To such ends, the UAV's ability to resist wind disturbances is identified as a reason for concern and is therefore the main focus of the design process. A model-based design approach is taken, to which an advanced multirotor simulator, realistic wind scenarios and a position control algorithm have been developed in the MATLAB Simulink environment. To enable study of different design setups and physical properties, the UAV model is made scalable. Applying knowledge from this investigation and other sources, a concept generation process is performed to determine a suitable concept.

I. INTRODUCTION

Multirotor UAVs have in recent years become a trend among engineers and hobbyists alike due to their simplicity and availability. Commercial uses range from surveillance to recreational flight with plenty of research being conducted at university level.

Application of multirotors in search and rescue missions is of main interest to this thesis. To ensure reliable performance for missions in all conditions, resistance to wind has been identified as a key factor. Hence, the aims of this thesis work is to provide a design able to withstand windy conditions

It is common in control engineering that the process is predetermined. Therefore, it is often not possible to influence its physical properties. In this design work, a model-based approach has been utilized. Using this, it can easily be modified in a simulated environment. Thus, control and mechanical design of the multirotor is performed in tandem, with benefits otherwise not attainable.

II. MULTIROTOR BASICS

A multirotor UAV is an unmanned aircraft that makes use of several propellers to control its movement through the air. It is typically quite small and present an exciting and challenging control problem. Unlike a conventional helicopter, it takes advantage of being able to manipulate the rotational speeds of each individual rotor. This enables a simple means to not only achieve upward thrust, but also rotate the aircraft around the three Cartesian axes.

In Figure 1 below, the four basic maneuvers are summarized, where the size of the circles and corresponding vertical arrows at each rotor indicate the rotor speed and thrust. The maneuvers are achieved by individually controlling each rotor's rotational speed, yielding an individual thrust force at each rotor. Moments can thus be created around each axis, resulting in roll, pitch and yaw rotation of the aircraft. A yawing moment is achieved by utilization of the rotational drag forces experienced by the propeller blades. A resulting reaction moment is translated through the multirotor body, thus achieving yaw rotation.

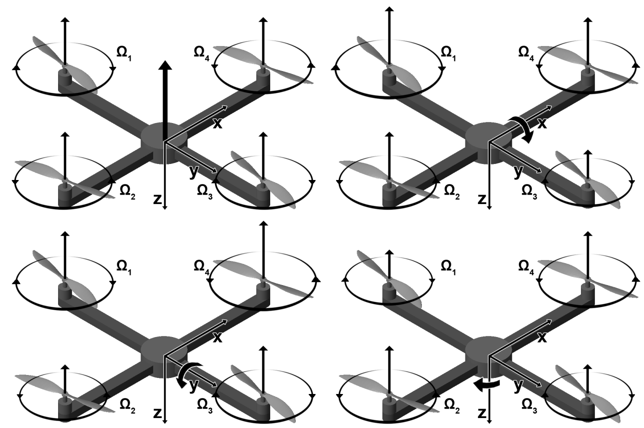

Figure 1: Thrust, roll, pitch and yaw maneuvers.

III. MODELING

An advanced multirotor simulator has been constructed using the MATLAB Simulink simulation environment. Thus, a mathematical model of the multirotor system was developed and implemented in this environment, providing an accurate flight description.

The key feature of the model is the rotor model. It makes use of helicopter theory [2, 3] to accurately describe the aerodynamic forces and moments acting at each rotor. Expressions for the rotor thrust T, horizontal force H and drag torque Q are given in (1), where ρ is the air density, A the rotor area, R the rotor radius and Ω the rotor rotational speed.

$$T = C_T \rho A R^2 \Omega^2 \quad H = C_H \rho A R^2 \Omega^2 \quad Q = C_Q \rho A R^3 \Omega^2 \quad (1)$$

The coefficients C_T, C_H and C_Q in (1) vary with the current flight state. To obtain these, a combination of momentum theory (MT) and blade element theory (BET) is used. In BET, forces and moments for each blade segment are integrated along the entire blade and over a full rotation of the rotor. However, BET requires the rotor induced velocity, which MT provides. In MT, the rotor airflow is modeled as a tube with a well-defined flow direction and boundary. MT and BET can be schematically described as in Figure 2.

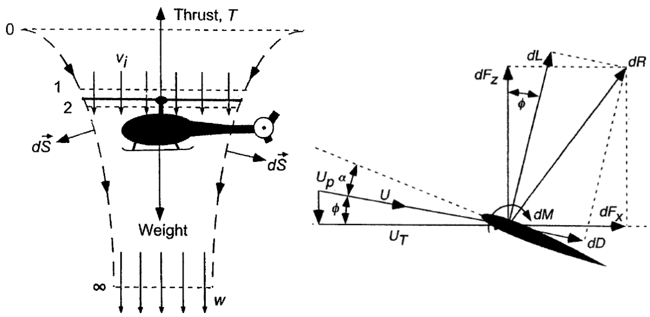

Figure 2: MT and BET are combined in the rotor model.

IV. Control

To achieve control of the multirotor position, the control structure in Figure 3 is proposed, inspired by [4, 5]. Since the rotors all face upwards, there are no direct means of horizontal flight. By letting an outer positional controller send desired angles as input to an attitude controller, position control is still achieved. In the figure, U_1 is the thrust, whereas U_2, U_3 and U_4 are rotational moments. They are achieved as shown by Figure 1.

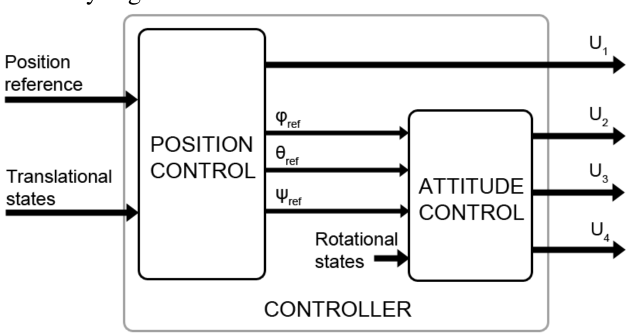

Figure 3: Controller structure.

V. Design

During the design phase of this thesis work, influence of size and mass of the multirotor was studied with a multifactor analysis approach [6]. To investigate how such quantities affect the aircraft's ability to resist wind, realistic wind scenarios were constructed based on theory used by the US Military [7]. Such a scenario is shown in Figure 4. It was concluded that a large total mass has a stabilizing effect on performance, but at a cost of energy-consumption. Also, the analysis indicated that a compact design is preferable.

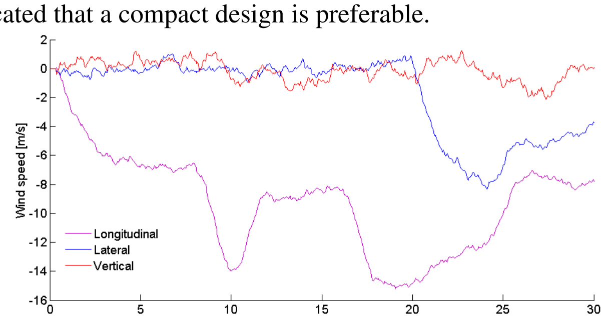

Figure 4: Wind test scenario.

Proceeding with the design, a number of concept were assembled and rated according to a concept generation and scoring process. Each concept was rated in regards to a number of criteria, most importantly wind resistance and power efficiency. After considerable research and consideration, a multirotor design as the one shown in Figure 5 was proposed. The coaxial rotors enable a large mass, whereas the three-armed body yields lower exposure to wind drag force.

Figure 5: Y6 design drawn with CAD.

VI. Conclusions

The contributions of this thesis work can be seen as a fore-study to a continuation of UAV research for search and rescue applications. Implementing the proposed design yields a reliable multirotor platform, which may be of great use to search parties. Attaching a thermal camera to the UAV and deploying several in packs will provide a powerful tool when searching for people lost in woods or other difficult terrain. With law enforcement agencies already looking into using UAVs for surveillance operations, applications like the ones focused on in this thesis work may not be far from being ready for real-world implementation and use.

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