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Development of advanced FDD and FTC techniques with application to an unmanned quadrotor helicopter testbed

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Abstract

As the first part, this paper presents an overview on the existing works on fault detection and diagnosis (FDD) and fault-tolerant control (FTC) for unmanned rotorcraft systems. Considered faults include actuator and sensor faults for single and multi-rotor systems. As the second part, several FDD and FTC techniques developed recently at the Networked Autonomous Vehicles Lab of Concordia University are detailed along with experimental application to a unique and newly developed quadrotor helicopter testbed.

1. Introduction

Over the last three decades, the growing demand for reliability and safety in engineering systems has drawn significant research and development in fault detection and diagnosis (FDD) and fault-tolerant control (FTC) [71]. Many effective methodologies and algorithms on FDD

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and FTC have been developed and with some successful applications as shown for example in several recently published books [39,7,44,33,20,3]. However, research and development of FDD and FTC still remain a challenging and active research area and with even wider and more practical applications to air and space vehicles such as civil transportation airplanes, unmanned aerial vehicles (UAVs), reusable launch vehicles, near space vehicles, satellites, etc. In particular, UAVs are gaining more and more attention during the last few years due to their important contribution and cost-effective application in several tasks such as surveillance, search, rescue, remote sensing, geographic studies, as well as various military and security applications. On the other hand, FDD and FTC research on manned aerial vehicles have a long history since the initial research on self-repairing flight control systems in US Air Force and NASA begun in mid-1980s [71]. However, experimental test and further practical research and development have been bounded due to safety concern and constraints. Benefited from the recent and significant advances of UAVs, development and application of FDD and FTC techniques have been emerged and developed quickly in recent years, since UAVs provide a cheap and operative experimental testbed for implementation, testing and validation of the newly developed FDD and FTC techniques. Furthermore, the above mentioned civilian applications will bring UAVs into difficult new situations such as flight in urban environments where reliability is particularly critical. The poor reliability of current unmanned vehicles presents a roadblock to their success in demanding new flight environments [15]. The Office of the Secretary of Defense acknowledges this shortcoming in the UAV Roadmap 2002–2027 [45]. It identifies the development of self-repairing, smart flight control systems as a crucial step in the overall advancement of UAV autonomy: "Improving UAV reliability is the single most immediate and long reaching need to ensure their success". Moreover, as stated in a latest IEEE report [58], "A further extension to DFBW (Digital Fly-By-Wire) flight control systems is to implement functions capable of compensating for aircraft damage and failure during flight, such as automatically using engine thrust and other avionics to compensate for severe failures-loss of hydraulics, loss of rudder, loss of ailerons, or loss of an engine" for future commercial aircraft and "automatic controller reconfiguration, allowing mission continuation or safe recovery following system failures or battle damage" for military aircraft and UAVs. It highlights also the need, future challenges for future commercial aircraft, military aircraft and UAVs to integrate with FTC capability as basic functions together with other existing functions.

This paper presents an overview on the existing research works towards improving UAVs reliability and safety. More specifically, it investigates the FDD and FTC methods that have been developed and applied to rotary-wing UAVs. Rotary-wing systems possess unique features and capabilities of vertical taking-off and landing, smaller area needed and easier flight testing compared with fixed-wing UAVs. Therefore, rotary-wing, including single-rotor, quad-rotor, and even octo-rotor UAVs have been becoming more and more popular recently as new testbeds for research and development of UAV techniques as well as more and more future practical applications. On the other hand, as pointed out also in [71], compared with fixed-wing aircraft, rotary-wing types of aircraft gained previously less attention in the research and development of FDD and FTC, mainly due to their highly non-linear feature and difficulty in control, with also less hardware redundancy available for example in single-rotor helicopters. It should be noted that upon analyzing the existing research works in the literature, the considered testbeds can be divided into two main categories: single rotor helicopters and four rotors helicopters (also known as quadrotors). The two subsequent sections provide a review on existing FDD/FTC works for each category. In Section 4 the newly developed quadrotor UAV, also known as Qball-X4, is presented.

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