

# Preface

Unmanned Aerial Vehicles (UAVs) or Unmanned Aircraft Systems (UAS), a term preferred by the U.S. Department of Defense, have seen unprecedented levels of growth over the last decade. Even though UAVs have been mainly used for military applications, there is a considerable and increasing interest for civilian applications. It is not an exaggeration to consider that as the technology matures, as small-scale UAVs become cost-effective with proven reliability and safety, and as the roadmap to integrating UAS into the National Airspace System (NAS) progresses, civilian applications will dominate the field. It is postulated that UAVs will be used in the future extensively for environmental monitoring, forest protection, wildfire detection, traffic monitoring, building, power line and bridge inspection, emergency response, crime prevention, search and rescue, mapping, surveillance, reconnaissance, border patrol, to name several applications.

From all classes of UAVs, unmanned rotorcraft, and in particular unmanned helicopters, have advantages over fixed-wing UAVs because they take-off and land vertically, they do not require a runway, and they have the ability to hover and fly in (very) low altitudes. It is reasonable to assume that light-weight ( $<150$  Kgr) and small-scale ( $<50$  Kgr) helicopters will be the first ones to be allowed to fly in civilian airspace. Such helicopters, though, still retain the flight characteristics and physical principles of their full-scale counterparts. In addition, they are naturally more agile and dexterous compared to full-scale helicopters. Their flight capabilities, reduced size and cost have recently monopolized the attention of the UAV research community as they are preferred for a wide spectrum of applications. However, helicopters are highly unstable, nonlinear and coupled underactuated systems, and controller design for such systems is a rather challenging problem.

The problem of designing autonomous flight controllers for small-scale helicopters is equally challenging, and the flight controller design problem is tightly connected with the helicopter modeling. Helicopter dynamics may be represented by both linear and nonlinear models of ordinary differential equations. Typically, the validity of the linear models is restricted in a certain region around a specific operating point, while nonlinear models provide a global description of the helicopter dynamics.

Therefore, it is the goal of this book to present a rather comprehensive and well justified analysis for designing (autonomous) controllers for small-scale unmanned helicopters, and then present details on how to design MIMO linear, continuous and discrete time nonlinear controllers for such helicopters guarantying stability. The controllers objective is for the helicopter to autonomously track predefined position (or velocity) and heading reference trajectories, evaluating their performance using *X-Plane*, a realistic and commercially available flight simulator.

However, as in most control applications, the helicopter model that is used for controller design purposes is just an approximation of the actual nonlinear helicopter dynamics. Thus, in order to develop a generic flight control system, which applies to most standard small-scale helicopter platforms, the designer must successfully solve three intermediate tasks: (i) Derive the structure and the order of a parametric dynamic model that best describes the helicopter motion; any derived parametric model should provide a physically meaningful dynamic description for a large family of small-scale helicopters. (ii) After the parametric helicopter model is derived, one must determine a nominal feedback control law such that the helicopter tracks a predefined reference trajectory. The design should guarantee that the control inputs remain bounded while the helicopter tracks the reference trajectory. (iii) Given a specific helicopter, one must determine which is the best methodology to accurately extract the values of the parametric model that will be used to implement the linear/nonlinear controllers.

The reader is introduced to the controller design challenges in a step-by-step way. At first, an analytical derivation of the helicopter's kinematic equations of motion is presented with the helicopter treated as a rigid body, followed by a simplified model of the main rotor dynamics that encapsulates the coupling effects between the fuselage motion and the main rotor of the helicopter. Next, the reader is introduced to linear controller designs based on a frequency domain identification method that is used for the extraction of low order linear helicopter models. Then, the focus shifts to controller designs based on the nonlinear helicopter model. The design approach is very rigorous and detailed following the backstepping methodology for systems in feedback form. Continuous and discrete time nonlinear controllers are presented, and a simple Recursive Least Squares (RLS) method is employed to identify the parameters of the discrete nonlinear helicopter model. It is also demonstrated how a Takagi–Sugeno fuzzy system may improve the time domain identification results of the RLS algorithm. An extensive comparison and evaluation of all controller designs is also included in this book. The rationale for such a study is to pave the way for a rather comprehensive performance evaluation of controllers, and at the same time justify and support the chosen methodologies.

The reader is expected to have knowledge of modern control theory as the minimum prerequisite to follow the book, as well as an understanding of fundamentals of kinematics and dynamics.

Atlanta, Georgia, USA  
Denver, Colorado, USA

Ioannis A. Raptis  
Kimon P. Valavanis

Linear and Nonlinear Control of Small-Scale Unmanned  
Helicopters

Raptis, I.A.; Valavanis, K.P.

2011, XXVI, 198 p., Hardcover

ISBN: 978-94-007-0022-2