The advance in robotics has boosted the application of autonomous vehicles to perform tedious and risky tasks or to be cost-effective substitutes for their human counterparts. Based on their working environment, a rough classification of the autonomous vehicles would include unmanned aerial vehicles (UAVs), unmanned ground vehicles (UGVs), autonomous underwater vehicles (AUVs), and autonomous surface vehicles (ASVs). UAVs, UGVs, AUVs, and ASVs are called UVs (unmanned vehicles) nowadays. In recent decades, the development of unmanned autonomous vehicles have been of great interest, and different kinds of autonomous vehicles have been studied and developed all over the world. In particular, UAVs have many applications in emergency situations; humans often cannot come close to a dangerous natural disaster such as an earthquake, a flood, an active volcano, or a nuclear disaster. Since the development of the first UAVs, research efforts have been focused on military applications. Recently, however, demand has arisen for UAVs such as aero-robots and flying robots that can be used in emergency situations and in industrial applications. Among the wide variety of UAVs that have been developed, small-scale HUAVs (helicopter-based UAVs) have the ability to take off and land vertically as well as the ability to cruise in flight, but their most important capability is hovering. Hovering at a point enables us to make more effective observations of a target. Furthermore, small-scale HUAVs offer the advantages of low cost and easy operation.

The Chiba University UAV group started research of autonomous control in 1998, advanced joint research with Hirobo, Ltd. in 2001, and created a fully autonomous control helicopter for a small-scale helicopter for hobbyists. There is a power-line monitoring application of UAV called SKY SURVEYOR. Once it catches power line, regardless of the vibration of the helicopter, with various on-board cameras with a gross load of 48 kg for a cruising time of 1 hour, catching of the power line can be continued. In addition, it has a payload of about 20 kg. Although several small UAVs are helicopters — Sky Focus-SF40 (18 kg), SST-eagle2-EX (7 kg), Shuttle-SCEADU-Evolution (5 kg), and an electric motor-based Lepton (2 kg) for hobbyists, with gross loads of 2–18 kg — fully autonomous control of these vehicles is already possible. Cruising time, depending on the helicopter’s class, is about 10–20 min, with payloads of about 800 g – 7 kg. These devices are what automated the commercial radio-controlled helicopters for
hobbyists, because they can be flown freely by autonomous flight by one person, are cheap and simple systems, and can apply chemical sprays, as in orchards, fields, and small-scale gardens. In the future they can also be used for aerial photography, various kinds of surveillance, and rescues in disasters.

GH Craft and Chiba University are conducting further research and development of autonomous control of a four-rotor tilt-wing aircraft. This QTW (quad tilt wing)-UAV is about 30 kg in gross load; take-off and landing are done in helicopter mode; and high-speed flight at cruising speed is carried out in airplane mode. Bell Helicopter in the United States completed development of the QTR (quad tilt rotor)-UAV, and its first flight was carried out in January 2006; however, the QTW-UAV had not existed anywhere in the world until now, although the design and test flight had been attempted. The QTW-UAV now is already flying under fully autonomous conditions. Moreover, Seiko Epson and Chiba University tackled autonomous control of a micro flying robot, the smallest in the world at 12.3 g, with the micro air vehicle (MAV) advantage of the lightest weight, and have succeeded with perfect autonomous control inside a room through image-processing from a camera. The XRB by Hirobo, Ltd., about 170 g larger than this micro flying robot, has also successfully demonstrated autonomous control at Chiba University. Flying freely with autonomous control inside a room has now been made possible.

We have also been aggressively developing our own advanced flight control algorithm by means of a quad-rotor MAV provided by a German company (Ascending Technologies GmbH) as a helicopter for hobbyists. We have chosen this platform because it offers good performance in terms of weight and payload. The original X-3D-BL kit consists of a solid airframe, brushless motors and associated motor drivers, an X-base which is an electronic card that decodes the receiver outputs and sends commands to motors, and an X-3D board that incorporates three gyroscopes for stabilization. The total weight of the original platform is about 400 g including batteries, and it has a payload of about 200 g. The flight time is up to 20 min without a payload and about 10 min with a payload of 200 g. The X-3D-BL helicopter can fly at a high speed approaching 8 m/s. These good characteristics are due to its powerful brushless motors that can rotate at very high speed. Furthermore, the propellers are directly mounted on the motors without using mechanical gears, thereby reducing vibration and noise. Also, our original 6-rotor MAVs for industrial applications such as chemical spraying have been developed, and their fully autonomous flight has already been successful.

For industrial applications, a power-line monitoring helicopter called SKY SURVEYOR has been developed. A rough division of the system configuration of SKY SURVEYOR consists of a ground station and an autonomous UAV. Various apparatuses carry out an autonomous control system of a sensor and an inclusion computer, and power-line monitoring devices are carried in the body of the vehicle. The sensors for autonomous control are a GPS receiver, an attitude sensor, and a compass, which comprise the autonomous control system of the model base. The flight of the compound inertial navigation of GPS/INS or a 3D stereo-vision base is also possible if needed. The program flight is carried out with the ground station or the embedded computer system by an orbital plan for operation surveillance,
if needed. For attitude control, an operator performs only position control of the helicopter with autonomous control, and so-called operator-assisted flight can also be performed. In addition, although a power-line surveillance image is recorded by the video camera of the UAV loading in automatic capture mode and is simultaneously transmitted to the ground station, an operator can also perform posture control of the power-line monitoring camera and zooming at any time.

We have been studying UAVs and MAVs and carrying out research more than 10 years, since 1998, and we have created many technologies by way of experimental work and theoretical work on fully autonomous flight control systems. Dr. Farid Kendoul worked 2 years in my laboratory as a post-doctoral research fellow of the Japan Society for the Promotion of Science (JSPS post-doctoral fellow), from October 2007 to October 2009. He contributed greatly to the progress in MAV research. These factors are the reason, the motivation, and the background for the publication of this book. Also, seven of my graduate students completed Ph.D. degrees in the UAV and MAV field during the past 10 years. They are Dr. Jinok Shin, Dr. Daigo Fujiwara, Dr. Kensaku Hazawa, Dr. Zhenyo Yu, Dr. Satoshi Suzuki, Dr. Wei Wang, and Dr. Dasuke Nakazawa. The last three individuals — Dr. Suzuki, Dr. Wang, and Dr. Nakazawa — along with Dr. Kendoul are the authors of this book.

The book is suitable for graduate students whose research interests are in the area of UAVs and MAVs, and for scientists and engineers. The main objective of this book is to present and describe systematically, step by step, the current research and development in, small or miniature unmanned aerial vehicles and micro aerial vehicles, mainly rotary wing vehicles, discussing integrated prototypes developed within robotics and the systems control research laboratory (Nonami Laboratory) at Chiba University. In particular, this book may provide a comprehensive overview for beginning readers in the field. All chapters include demonstration videos, which help the readers to understand the content of a chapter and to visualize performance via video. The book is divided into three parts. Part I is “Modeling and Control of Small and Mini Rotorcraft UAVs”; Part II is “Advanced Flight Control Systems for Rotorcraft UAVs and MAVs”; and Part III is “Guidance and Navigation of Short-Range UAVs.”

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