ZRÍNYI MIKLÓS
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ONBOARD FLIGHT CONTROS SYSTEM OF AN UNMANNED QUAD-ROTOR HELICOPTER

PhD thesis brochure

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Introduction

The geopolitical changes and the technological evolution at the end of the 20th century lunched a new era in military engineering. In these days' military conflicts, where the informational dominance has great importance, the armies with great strength have replaced with smaller military forces equipped with high precision weapons and up to date computer and robot technology. Providing an efficient way of information acquisition unmanned aerial vehicles (UAV) have become important part of advanced warfare. The main reason of this fact is the protection of lives. Loss of a UAV only means damage to property not loosing a life. This is also more acceptable to the public. On the other hand there is no need to limit the maneuverability of the airplane because of human in the cockpit. Accordingly, UAVs can operate in such conditions that are hazardous or dangerous to man.

Other important reason why more and more UAVs are in service in modern armies is the expenses. The production, the operation, the maintenance and the training of the operators of UAVs are far cheaper than those of the piloted ones. Since recent advances in control theory and technology made it possible to reliably automate most of flying functions, the operator can concentrate on the objective of the mission.

Some special application requires vertical take-off and landing (VTOL) capacity. These kinds of airplanes do not need long runway therefore can operate without significant background support. Hence, a small size VTOL UAV equipped with suitable onboard sensors can effectively assist close range military intelligence and surveillance missions without jeopardizing human lives.

Recently a number of research groups are again investigating the problem of developing a small four-rotor helicopter design. A single rotor helicopter is very dangerous in an indoor or obstacle bounded environment because of the potential for the exposed rotor blades to collide with something and cause the helicopter to crash. Even skilled pilots have trouble navigating them close to the outside of buildings. Four-rotor helicopters are attractive because the rotors are smaller and can be enclosed, making them safer. Also, it may be possible to achieve more stationary hovering with four thrust forces acting at a distance from the centre of gravity than with one force acting through the centre of gravity. A small electrical four-rotor helicopter owing to its mechanical simplicity can be a robust and reliable VTOL UAV construction.

To facilitate the job of the pilot, it is rewarding to automate some functions of the UAV. Manually stabilizing the flight of a four-rotor helicopter by means of controlling the speed of the four rotors is almost impossible. Accordingly the use of an onboard autopilot is necessary to utilize this construction in UAV applications. Besides, the autopilot can provide stable platform for onboard imaging sensors and opportunity to accomplish out of sight operations.

Objectives

1. Determine the nonlinear mathematical model of the four rotor helicopter, including the inertia tensor and the dynamical model of the electrical drives.
2. After the investigation of the commercially available autopilots, design an onboard flight control system that is capable of stabilizing the experimental four-rotor UAV. Taking into account the computational demands and my resources construct the onboard electronics.
3. From the nonlinear mathematical model determine the linear model in near hover flight.
4. Utilizing the linear model of the helicopter and the electrical drives, design a flight controller and a motor-controller, implemented in the onboard electronics, that are capable of stabilizing the flight of the experimental four-rotor helicopter in small angel maneuvers.

Methods of research

I have accomplished a vast of research work in literature related to the subject of my thesis. Examining and analyzing the theoretical and practical achievements published in books, in articles and over the internet I have improved my knowledge. I have consulted experts and professionals in aviation in control theory and electronics. I have attended scientific conferences and lectures as lecturer and also as audience. I have regularly published my achievements in technical journals and conference proceedings. I have accomplished experiments, measurements and simulations to determine and tune the parameters of my system.

Structure of the thesis

1st chapter: I investigate the applicability of the four-rotor helicopter design then I state its physical equations. I provide a solution to approximate the inertia tensor. I determine the mathematical model of the electrical drives and in conclusion I state the nonlinear mathematical model of the entire system.

2nd chapter: After the examination of two commercially available autopilot systems I work out the structure of the onboard electronics of the experimental four-rotor helicopter. I demonstrate the sensors, the communication devices, the central processing unit and the implemented onboard and ground software.

3rd chapter: I summarize the methods of classical and modern control theory and I investigate their applicability in my controller problem. I design the controllers of the electrical motor drives. Utilizing the nonlinear model I determine the linear model of the experimental four-rotor helicopter in near hover flight and I design a linear flight controller. I demonstrate the controller parameter tuning procedure and the results of the simulations. I present the results of the test flights and the final controller architecture.

Conclusions

Due to the hovering capability, the robust construction and the silent operation the four-rotor helicopter is a suitable platform in military intelligence, surveillance and reconnaissance UAV applications.

In order to design a stabilizing flight control system an adequate mathematical model has to be determined that mimic the real behavior of the helicopter. From the result of the simulations and the successful test flights it can be stated that my method of approximation of the inertia tensor is appropriate, and the mathematical model of the electrical motor drives and the nonlinear model of the entire system is suitable for control system design.

In order to implement the flight control system in an onboard hardware the state variables have to be adequately measured and a suitable central processing unit has to be selected. Hence in my experimental onboard electronics I use small inertial and other navigation sensors and digital signal processor.

Utilizing the nonlinear model I determined the linear model of the helicopter near hover. Employing the results of the simulations I designed a PI motor controller and an LQG flight controller. After the test flights I realized that the controller structure has to be modified due to the inadequate sensor data. With the final controller structure the flight of the experimental system can be stabilized in small angle maneuvers.

From the results of the test flights I concluded that the designed and constructed experimental flight control hardware and software components can stabilize the four-rotor helicopter in near hover maneuvers. To achieve a fully autonomous flight it is necessary to use additional onboard sensors which can measure precisely the x-y position.

Thesis

1. I determined the nonlinear mathematical model of the experimental four-rotor helicopter design, including the inertia tensor and the dynamical model of the electrical drives.
2. After the investigation of the commercially available autopilots, I designed an onboard flight control system that is capable of stabilizing the experimental four-rotor UAV. Taking into account the computational demands and my resources I constructed the onboard electronics.
3. From the nonlinear mathematical model I determined the linear model of the four rotor helicopter in near hover flight.
4. Utilizing the linear model of the helicopter and the electrical drives, I designed a flight controller and a motor-controller, implemented in the onboard electronics that are capable of stabilizing the flight of the experimental four-rotor helicopter in small angel maneuvers. With the flight control system the four rotor helicopter can provide stable platform for onboard imaging sensors.

Recommendations

In respect that the four-rotor VTOL UAV can be a suitable platform in many military and civilian applications I propose further inland development of the presented experimental system. Considerable improvement can be achieved in quality and reliability with the use of three phase brushless motors, with navigation by means of onboard image processing, with GPS and so on. Besides I recommend replacing and strengthening the enclosure and the whole mechanical construction. These topics can start further research works.

List of publications

Articles in Hungarian

1. **Turóczi, Antal:** *Önjáró robotok fedélzeti helyzet-meghatározó eszközei,* Repüléstudományi közlemények, XV. évfolyam 35. szám, p185-194, 2003.
2. **Turóczi, Antal:** *Pilóta nélküli légi járművek navigációs berendezései,* Bolyai Szemle, 2006. 1. szám p179-193.
3. **Turóczi, Antal:** *Katonai alkalmazású robotok villamos meghajtása,* GÉP folyóirat, LVII. évfolyam, 2006/5. p44-52.
4. **Turóczi, Antal:** *Négyrotoros pilóta nélküli helikopter fedélzeti automatikus repülésszabályzó rendszerének tervezése,* Hadmérnök, Különszám: Robothadviselés 6, http://zrinyi.zmne.hu/hadmernok/
5. **Turóczi, Antal:** *Négyrotoros pilóta nélküli helikopter fedélzeti elektronikai rendszere,* Hadmérnök Különszám: Robothadviselés Tudományos Konferencia 2007. http://zrinyi.zmne.hu/hadmernok/
6. **Turóczi, Antal:** *Jelfeldolgozás digitális műholdas kommunikációs rendszerekben,* Hadmérnök III. évfolyam 1. szám 2008. március, http://zrinyi.zmne.hu/hadmernok/
7. **Turóczi, Antal:** *Négyrotoros pilóta nélküli helikopter fedélzeti repülésszabályzójának előzetes tervezése LQG módszerrel,* Repüléstudományi közlemények különszám: Repüléstudományi konferencia 2008.

Articles in English

1. **Imre Makkay, Antal Turóczi:** *Onboard Electronics of UAVs,* AARMS, Volume 5, Issue 2, 2006. p237-243.

Lectures in Hungarian

1. **Turóczi Antal:** *Önjáró robotok fedélzeti elektronikai rendszerei,* Százéves a Magyar Géprepülés konferencia, Szolnok, 2003. Április 4.
2. **Turóczi Antal:** *Pilóta nélküli légi járművek navigációs berendezései,* Robothadviselés 5. tudományos konferencia, Budapest, 2005.
3. **Turóczi Antal:** *Négyrotoros pilóta nélküli helikopter fedélzeti automatikus repülésszabályzó rendszerének tervezése,* Robothadviselés 6. Tudományos Szakmai Konferencia, Budapest, 2006.

4. **Turóczi Antal:** *Négyrotoros pilóta nélküli helikopter matematikai modelljének meghatározása,* Tavaszi Szél konferencia-kiadvány 2007 p134-143, Doktoranduszok Országos Szövetsége, 2007.
5. **Turóczi Antal:** *Négyrotoros pilóta nélküli helikopter fedélzeti elektronikai rendszere,* Robothadviselés Tudományos Konferencia 2007. november 27.

Lectures in English

1. **Dr. Imre Makkay, Antal Turóczi:** *Hungarian Solution for Advanced Tactical UAVs,* in: UAV and UCAV Symposium „Threats and Possibilities in Future Networked Defences" MAY 22nd and 23rd 2003 in Stockholm, Sweden, CD melléklet
2. **Dr. Imre Makkay, Andras Molnar, Antal Turóczi:** *Stabilization concepts of UAVs,* in: 9th UAVNET Meeting 26-27 January 2004, Amsterdam, http://www.uavnet.com/DL/Document_Library/Amsterdam_Meeting/UAV_stabilization_Makkay.pdf
3. **Miklós Koncz, Antal Turóczi:** *Autopilot applications for different UAV airframes,* in: 11th UAVNET Meeting 6-7 September 2004 in Budapest, Hungary, http://www.uavnet.com/DL/Document_Library/Budapest_Meeting/Autopilot_Koncz.pdf

Curriculum Vitae

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Education:

- Zrínyi Miklós National Defense University, PhD Institute in Military Technology
- 1996-2002: Budapest University of Technology an Economics, Feculty of Electrical Engineering and Informatics (Information Technology)
- 1992-1996: Bólyai János Secondary School of Electronics, Budapest

Lenguage skills:

- English: Hungarian Intermediate State Examination, type C
- Spanish: Hungarian Elementary State Examination, type C

Computer skills:

Office (Word, Excel, PowerPoint), CorelDraw,
CAD and development tools:
Orcad (Capture, PSpice, Simulate, Layout), Xilinx CPLD - FPGA SDK,
Analog Devices Visual DSP++
Programming languages:
C, C++, Assembly (Atmel AVR, TMS320Cxxxx, ADSP21xx, Intel), Matlab,
Maple, VHDL, Pascal

Employment:

- 1998 - Bizalom Vagyonvédelmi Rt., Budapest, Administrator, Security and Informatics System designer

Scientific activities:

- Development of a 3D ultrasonic positioning system, Budapest University of Technology and Economics, 2002
- Research an development of onboard electronics of UAVs
- Development of embedded software and hardware component (DSP, FPGA systems)
- Development and implementation of telecommunication algorithms