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Structural damage detection using randomized trained neural networks

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Abstract

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Abstract

A computational method on damage detection problems in structures was developed using neural networks. The problem considered in this work consists of estimating the existence, location and extent of stiffness reduction in structure which is indicated by the changes of the structural static parameters such as deflection and strain. The neural network was trained to recognize the behaviour of static parameter of the undamaged structure as well as of the structure with various possible damage extent and location which were modeled as random states. The proposed techniques were applied to detect damage in a cantilever beam. The structure was analyzed using finite-element-method (FEM) and the damage identification was conducted by a back-propagation neural network using the change of the structural strain and displacement. The results showed that using proposed method the strain is more efficient for identification of damage than the displacement. © 2009 Springer-Verlag Berlin Heidelberg.

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Preface

The book largely represents the extended version of select papers from the International Conference on Intelligent Unmanned System ICIUS 2007 which was jointly organized by the Center for Unmanned System Studies at Institut Teknologi Bandung, Artificial Muscle Research Center at Konkuk University and Institute of Bio-inspired Structure and Surface Engineering, Nanjing University of Aeronautics and Astronautics. The joint-event was the 3rd conference extending from International Conference on Emerging System Technology (ICEST) in 2005 and International Conference on Technology Fusion (ICTF) in 2006 both conducted in Seoul. ICIUS 2007 was focused on both theory and application primarily covering the topics on robotics, autonomous vehicles and intelligent unmanned technologies. The conference was arranged into three parallel symposia with the following scope of topics:

Unmanned Systems: Micro air vehicle, Underwater vehicle, Micro-satellite, Unmanned aerial vehicle, Multi-agent systems, Autonomous ground vehicle, Blimp, Swarm intelligence, learning and control

Robotics and Biomimetics: Artificial muscle actuators, Smart sensors, Design and applications of MEMS/NEMS system, Intelligent robot system, Evolutionary algorithm, Control of biological systems, AI and expert systems, Biological learning control systems, Neural networks, Genetic algorithm

Control and Intelligent System: Distributed intelligence, Distributed/decentralized intelligent control, Distributed or decentralized control methods, Distributed and embedded systems, Embedded intelligent control, Complex systems, Discrete event systems, Hybrid systems, Networked control systems, Delay systems, Fuzzy systems, Identification and estimation, Nonlinear systems, Precision motion control, Control applications, Control engineering education.

The book is organized into three parts which reflect the spectrum of the conference themes. The first part of the book consists of five chapters dealing with the study of unmanned systems. Space applications of unmanned systems are presented in the first two chapters. Chapter 1 deals with the application of image processing algorithm for the autonomous guidance of lunar probe. A new approach using computer vision is proposed for providing precise motion estimation for probe landing. The purpose of the image algorithm is to detect and track feature points which are factors of navigation. In this chapter, the algorithm is illustrated as two steps: firstly, fixation areas are detected as sub-images and matched. Secondly, feature points are extracted from sub-images and tracked. Computer simulation demonstrates the result of algorithm takes less computation and fulfils requirements of navigation algorithm. Chapter 2 discusses classification of locomotion mechanism of intelligent unmanned explorer for deep space exploration. The chapter provides the comparison of the speed of hopping and wheeled robots and some simulation studies are performed to analyze the detailed mobility of wheeled robots.

The rest of the Part I center on the modeling, control and guidance for rotorcraft-based unmanned aerial vehicle. Chapter 3 addresses the need for global linear models of a small scale helicopter for control design. This chapter presents a step by step development of linear model for small scale helicopter based on first-principle approach. Beyond the previous work in literatures, the calculation of the stability derivatives is presented in detail. A computer program is used to solve the equilibrium conditions and then calculate the change in aerodynamics forces and moments due to the change in each degree of freedom and control input. Chapter 4 deals with the implementation of a novel control technique combining algebraic approach and LQ design. The viability of the method is demonstrated for hovering control of small-scale helicopter simultaneously subjected to plant parameter uncertainties and wind disturbances. Chapter 5 discusses the control strategy for four-rotor vertical take-off and landing (VTOL) aerial robot called X4-flyer. The kinematics control law is first derived using Astolfi's discontinuous control. A backstepping control method is then introduced providing the kinematic based inputs to construct the torque control of X4-flyer. The effectiveness of the approach is demonstrated through computer simulations.

The second part of the book deals with diverse issues in robotics and biomimetics. Chapter 6 introduces an insect-inspired flapper device mimicking general characteristics of flying insects. The flapper was actuated by a unimorph piezoelectric composite actuator and a compressed one, respectively, for force generation comparison. The chapter discusses flapping tests which were conducted both in the air and in a vacuum chamber to measure total vertical force and vertical inertia force. The optimal operation of the flapper is corroborated experimentally. Chapter 7 presents successful development on bio-mimetic wing design inspired from cicada. The aerodynamic force measurement, wing kinematics observation and wind tunnel test were conducted to evaluate the performance between normal wing and bio-mimetic wing. It was shown that the bio-mimetic wing is superior to the normal wing in terms of not only force generation but also the aspect of appropriate wing kinematics. Chapter 8 deals with application of multiple mobile robot types for management of environmental conditions. The authors propose a system which consists of a database center and various autonomous robots, each with different functions to allocate robots to manage environmental conditions. The overall concept and several important features of the proposed system are described. The study also proposes a position estimation method and explains the performance evaluation through experiments. In Chapter 9, the authors present a study of locomotion elicited by electrical stimulation in the mesencephalon of lizard Gekko gecko. Their results show that it is possible to carry-out artificial induction on Gekko gecko through electrical stimulation on the related nucleus in their brain. Chapter 10 discusses a concept of intelligent mechanical design for autonomous mobile robot. The design principle provides the guidance for investigating mechanics' self-controllability, reliability, realizability, and compatibility for autonomous mobile robot. Chapter 11 is focused on a method for mobile robot path planning to a destination and obstacle avoidance based on neural network and genetic algorithm. The avoidance action of a wheeled type robot is determined from the obstacle configuration, the robot's self-state and destination information using a neural network where the design parameter is adjusted by using genetic algorithm. The effectiveness of present method is proved through a simulation.

Part III covers topics in control theory and intelligent system. Chapter 12 discusses the use of virtual reality simulation for robot design to meet certain criteria. The approach is emphasized through the simulation of Fire Fighting Robot in order to evaluate the performance of the robot design in meeting some of the contest rules such as navigating in a labyrinth arena without hitting walls, quickly extinguishing a flame in a room and return home. In Chapter 13, the authors study an important class of dynamics systems called under-actuated systems arising in robot manipulator. Monotonic decreasing energy and switching control are utilized to control such a system. Chapter 14 discusses feedback control system in which plant's sensors and actuators are connected to controller through a communication network. The technique extends point-to-point wired configuration found in conventional feedback control. Specifically, the authors address the synthesis of networked control systems that satisfy passivity requirements using linear matrix inequality approach. Chapter 15 deals with controlled switching dynamical systems using linear impulsive differential equations. The authors investigate a unified approach to analysis and to design the switching controller by formulating the phenomena as a hybrid system using linear impulsive differential equation representation. State jumps and mode changing of the controller responding to switched of plant dynamics are exploited and discussed. The switching controller is designed by using LMI method that will guarantee H_2-type cost and implemented to a mini scale helicopter due to its complex dynamic and changing modes operation between hover and cruise. Chapter 16 discusses the use of neural networks for structural damage detection. The neural network was trained to recognize the behavior of static parameter of the undamaged structure as well as of the structure with various possible damage extent and location which were modeled as random states. The proposed techniques were applied to detect damage in a cantilever beam. The structure was analyzed using finite-element-method (FEM) and the damage identification was conducted by a back-propagation neural network using the change of the structural strain and displacement. Chapter 17 focuses on a methodology for simultaneous identification of fault parameters and mode switching events for hybrid systems. The authors propose a method based on the notion of Global Analytical Redundancy Relations (GARR) from the bond graph model of the hybrid system. A unified formula with mode change time sequence and initial mode coefficients (IMC) is derived to represent the mode switching. Fault parameters, mode switching time stamps and all IMC are encoded into one chromosome as a potential solution of the identification process. An electro-hydraulic system of vehicle is studied to illustrate the efficiency of the proposed algorithm.

The book covers multi-faceted aspects of intelligent unmanned systems. A wide array of relevant theory and applications are presented to address the current and future challenges in the area of unmanned systems. The editors would like to express their sincere appreciation for all the contributors for the cooperation in producing this volume. Chapter 17 represents a contributed paper beyond the context of the conference. The contribution from the invited authors is gratefully acknowledged. Overall, all authors are to be congratulated for their efforts in preparing such excellent chapters. The editors wish that the readers from all relevant background will find this book not only stimulating but also useful and usable in whatever aspect of unmanned system design they are involved with and that it can inspire further advancement in other related research areas.

Agus Budiyono
Bambang Riyanto
Endra Joelianto

Contents

Structural Damage Detection Using Randomized Trained Neural Networks

Ismoyo Haryanto[1], Joga Dharma Setiawan[1], and Agus Budiyono[2]

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Abstract. A computational method on damage detection problems in structures was developed using neural networks. The problem considered in this work consists of estimating the existence, location and extent of stiffness reduction in structure which is indicated by the changes of the structural static parameters such as deflection and strain. The neural network was trained to recognize the behaviour of static parameter of the undamaged structure as well as of the structure with various possible damage extent and location which were modeled as random states. The proposed techniques were applied to detect damage in a cantilever beam. The structure was analyzed using finite-element-method (FEM) and the damage identification was conducted by a back-propagation neural network using the change of the structural strain and displacement. The results showed that using proposed method the strain is more efficient for identification of damage than the displacement.

Keywords: back-propagation, damage detection, finite element method, neural network.

1 Introduction

Structural systems or machinery components tend to accumulate damage during their operation life. Therefore, an effective and reliable damage assessment methodology of the structural system is a very valuable tool. A determination of safety level of a structural system during its operational life is essential not only for safe operation but also maintenance cost reduction and failure prevention.

Occurrence of damage in a structural element reduces stiffness of the structure and generates a small perturbation in its static or dynamic responses. A perturbation on static responses can be identified by the behaviour of displacements or strains. Meanwhile, the behaviour of natural frequencies and mode shapes can be used to identify the perturbation on dynamic responses of the structure. A combination of measured response and finite-element-methods (FEM) then can be developed in order to identify these response perturbations which can be used to determine the size and location of the damage of the structure.

Response of damaged structure will follow the pattern of the size and location of the damage on its structure. Bishop has shown that this pattern can be generalized

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An Insect-Like Flapping-Wing Device Actuated by a Compressed Unimorph Piezoelectric Composite Actuator

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Abstract. In this work, we have introduced an insect-inspired flapper mimicking typical general characteristics of flying insects such as wing corrugation and wing clap-fling as well as wing rotation. The flapper was actuated by a unimorph piezoelectric composite actuator and a compressed one, respectively, for force generation comparison. Flapping tests were conducted both in the air and in a vacuum chamber to measure total vertical force and vertical inertia force, and then the vertical aerodynamic force was calculated by subtracting the vertical inertia force from the total vertical force. Further, the wing kinematics of the flapper was figured out by examining high-speed camera images taken from front and top views at the same time. The experimental results confirmed that the flapper could optimally operate at flapping frequency of 9 Hz and applied voltage of 300 voltage peak-to-peak (V_{pp}). In addition, the results also showed that we could increase the flapping angle 22 % and improve the average of vertical aerodynamic force 19 % by using the compressed piezoelectric composite actuator.

1 Introduction

Flying insects are the only group of invertebrates to have evolved powered flight over the past several million years of evolution. They have many fascinating features of flight and maneuverable abilities that are superior to any man-made flying vehicles in many ways: flying insects have capability of long-time hovering, quick maneuver, instantly dart sideways or backward, and effectively discontinuous changes of direction, etc. Typically, the flapping frequency of insects ranges from a few hertz to hundreds hertz; as flapping frequency increases their body weight increases and their wing area decreases. From the viewpoint of aerodynamics, flying insects can produce relatively high lift and thrust and fly in the low Reynolds number regime ranging from 5 to 10,000 [1], where effect of the viscous force is dominant. In engineering

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Locomotion Mechanism of Intelligent Unmanned Explorer for Deep Space Exploration

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Abstract. In recent years, such small body exploration missions as asteroids or comets have received remarkable attention in the world. In small body explorations, especially, detailed in-situ surface exploration by tiny rover is one of effective and fruitful means and is expected to make strong contributions towards scientific studies. Performance of mobility on surface explorer is highly dependent on the gravitational environment. Some researchers have proposed novel locomotion mechanisms for extremely small terrestrial bodies like asteroids. Hopping is a possible method under micro-gravity. It is not proved, however, that the proposed method of locomotion is optimum for a given level of gravity. The purpose of this paper is to analyze which level of gravity is optimum for each mechanism, and which mechanism or parameter is optimum for each level of gravity. This paper discusses classification of locomotion mechanism. This paper compares the speed of hopping and wheeled robots and some simulation studies are performed to analyze the detailed mobility of wheeled robots.

1 Introduction

Small planetary bodies such as asteroids, comets and meteorites in deep space have received worldwide attentions in recent years. These studies have been motivated by a desire to shed light on the origin and evolution of the solar system. Hence, exploration missions for small bodies have been carried out continuously since the late 1990s. To date, the missions of NEAR [1], Deep Space 1 [2], Deep Impact [3], and Stardust [4] have been successfully performed, while MUSES-C [5] and Rosetta [6] are currently in operation. These missions have mainly provided remote sensing in the vicinity of the small body, at a distance which cannot be attained from the earth. In-situ observations of small bodies are scientifically very important because their sizes are too small to have experienced high internal pressures and temperatures, which means they should preserve the early chemistry of the solar system. For future missions, in-situ surface observation by robots will make strong contributions towards those studies.

Small bodies such as asteroids and comets have an extra low gravitational environment. Some researchers have proposed robots with hopping mechanism in order to perform scientific observation on a large number of sites on such small bodies [7-16] as shown in Figure 1. For example, a hopping rover called MINERVA [17-25], which was a part of the Hayabusa mission [5] of ISAS/JAXA, was taken to the asteroid Itokawa. MINERVA can hop on the surface in micro gravity environment by using

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