HYBRID FAULT DETECTION USING KALMAN FILTER AND NEURAL NETWORK FOR QUADROTOR MICRO AERIAL VEHICLE

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SUPERVISOR'S DECLARATION

We hereby declare that we have checked this thesis and in our opinion, this thesis is adequate in terms of scope and quality for the award of the degree of Master of Science.

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I hereby declare that the work in this thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at University Malaysia Pahang or any other institutions.

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LIST OF SYMBOLS

ϕ	Roll
θ	Pitch
Ψ	Yaw
x	Location in x axis
y	Location in y axis
z	Location in z axis
$\dot{q}_i$	Generalized coordinate
Γ_i	Generalized force
V	Velocity
t	Time in second
Ω	Omega
τ	Torque
I_{xx}	Quadrotor moment of inertia around X axis
I_{yy}	Quadrotor moment of inertia around Y axis
I_{zz}	Quadrotor moment of inertia around Z axis
Jr	Total rotational moment of inertia around the propeller axis
b	Thrust factor
d	Drag factor
l	Distance to the center of the Quadrotor
m	Mass of the Quadrotor in Kg
g	Gravitational acceleration
c	Cosine
s	Sine
u	Control output
Re	Residual
Loc	Location

LIST OF ABBREVIATIONS

ANN	Artificial Neural Network
B	Body fixed frame
BP	Back-propagation
CoG	Centre of gravity
DC	Direct current
DES	Discrete-event system
DOF	Degree of Freedom
E	Earth fixed frame
FD	Fault diagnose
FDI	Fault Detection and Isolation
FDIR	Fault diagnosis, isolation, and recovery
KF	Kalman Filter
LOE	Loss of effectiveness
LQE	Linear quadratic estimation
NUVs	Network of unmanned vehicle
PD	Proportional–Derivative
PID	Proportional–Integral–Derivative
PWM	Pulse Weight Modules
TSKF	Two-Stage Kalman Filter
UAVs	Unmanned aerial vehicles

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ABSTRAK

Tesis ini bertujuan untuk membincangkan kebolehgunaan kaedah Pengesanan Kesalahan Sempadan Hibrid (FD) domain masa untuk Kenderaan Udara Mikro quadrotor (MAV). Aplikasi ini bertujuan untuk menyelesaikan salah satu masalah utama quadrotor, iaitu ketidakupayaan untuk mendapatkan lokasi sasaran yang tepat. Antara masalah yang boleh berlaku adalah kerosakan isyarat di sensor atau sebelah penggerak atau kedua-duanya, yang menyebabkan quadrotor tidak dapat menyelesaikan tugas yang diberikan. Antara sebab-sebab isyarat yang rosak adalah ralat isyarat dalam quadrotor, dalam sensor atau sebelah penggerak, serta masalah komunikasi. Apabila terdapat ralat penggerak, sensor atau kedua-duanya, pengawal tidak boleh berfungsi dengan baik dan seterusnya mengurangkan prestasinya. Pada peringkat awal reka bentuk kawalan awal quadrotor, ia biasanya akan direka di bawah andaian bahawa tiada kesalahan akan berlaku dalam quadrotors. Oleh itu, kaedah Pengesanan Kesalahan Sempadan Hibrid (FD), adalah penting untuk memastikan sistem quadrotor boleh berfungsi dengan baik dan cekap. Dalam kajian ini, kita telah menggunakan teknik hibrid yang menggabungkan penapis dilanjutkan Kalman dan Model Rangkaian Neural Tiruan (ANN). Tesis ini juga menganalisis Dua kelas pendekatan, iaitu pendekatan pengenalan sistem ANN, dan pendekatan berasaskan pemerhati menggunakan penapis Kalman. Untuk penyelidikan ini, Model Rangkaian Neural Tiruan (ANN) telah direka dan digunakan sebagai simulasi tingkah laku dalam sistem untuk menguji kesemua keadaan kegagalan. Pertama sekali, Penapis Kalman akan mengenal pasti data dari sensor sistem dan menunjukkan kesalahan sistem dalam bacaan sensor. Ramalan ralat adalah berdasarkan magnitud kesalahan dan masa berlakunya kesalahan. Maklumat tersebut kemudiannya akan diberi kepada ANN, yang terdiri daripada bank anggaran parameter yang menghasilkan keadaan kegagalan. ANN adalah algoritma yang digunakan untuk menentukan jenis kesalahan, mengasingkan kesalahan dalam sistem dan menentukan tahap keseruisan kesalahan tersebut. ANN direka berdasarkan Rangkaian Autoregressive Nonlinear dengan Skema Input Eksternal (NARX) supaya ia dapat dilatih untuk menghasilkan output berdasarkan perilaku simulasi quadrotor. Hasil dari isyarat sisa sebelum ditapis dan selepas ditapis menunjukkan bahawa Kalman-ANN dapat mengenalpasti ralat dengan segera serta membetulkan sistem kepada keadaan normal. Bagi semua kesalahan individu termasuk kesalahan, ketepatan pengesanan adalah 78,89 peratus. Kesimpulan nya, bahawa kaedah hibrid FD baru yang dicadangkan dalam tesis ini dapat mengesan dengan tepat kesalahan lokasi, untuk kedua-dua sensor dan penggerak kesalahan serentak dalam quadrotor itu.

Kata kunci: Quadrotor, Kalman filter, Rangkaian Neural Buatan, Pengesanan Kesalahan, Pengasingan Kesalahan, Kalman-ANN, Kalman-Fuzzy, Rangkaian Autoregressive Nonlinear dengan Input Eksogen.

ABSTRACT

This thesis introduces the application of time-domain Hybrid Fault Detection (HFD) methods for application in a quadrotor Micro Aerial Vehicle (MAV). The application aims to solve one of the main problems of the quadrotor, which is its inability to reach the exact target location that the user intended. The problem may be due to a faulty signal happened in the sensor or the actuator side or both, causing the quadrotor unable to complete the task given. Among the reasons of the faulty signal are the occurrences of signal in quadrotor, in the sensor or actuator side, as well as possible communication problem. When actuator fault, sensor fault or both faults occur, the controllers cannot function well and hence its performance reduce. At the initial control design stage of quadrotor, it is usually designed under the assumption that no faults would occur in quadrotors. The Faulty Detection (FD) method is therefore crucial to ensure quadrotor system can work properly and efficiently. The proposed method for the fault detection in this study uses hybrid technique which combines the extended kalman filter and artificial neural network (ANN). Two classes of approaches are analysed: the fault system identification approach ANN and the observer-based approach using the extended kalman filter. The extended kalman filter recognizes data from the sensors of the system and indicates the residuals of the system in the sensor reading. Residuals prediction is based on the fault magnitude and the time occurrence of fault. The information will then be fed to ANN, which consists of a bank of parameter estimation that generates the failure state. ANN is an algorithm that is used to determine the fault condition and determine its severity in the quadrotor system. ANN is designed based on nonlinear autoregressive network with exogenous inputs (NARX) scheme so that it can be trained to generate output based on the simulation behaviours of the quadrotor. The different fault locations are used as input vectors for training an artificial neural network (ANN). The result of the residual signal before filtration and after filtration showed that Kalman-ANN is able to identify single fault as well as multiple faults. For all individual faults including the multiple fault detection, the accuracy of the detection is 78.89 percent. It can be conclude that the newly proposed hybrid FD method in this thesis is able to accurately detect the location fault, for both the sensor and actuator faults simultaneous in the quadrotor.

Keywords— Quadrotor, Kalman filter, Artificial Neural Network, Fault Detection, Fault Isolation, Kalman-ANN, Kalman-Fuzzy, Nonlinear Autoregressive Network with Exogenous Inputs.

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