# Fault Detection Using Neural Network in Tilt Rotor

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**ABSTRACT**

**System faults, which usually lead to changes in critical system parameters or even system dynamics, may lead to degraded performance and unsafe operating conditions. Fault detection plays an important role in ensuring system safety and reliability for unmanned aerial vehicles. Artificial neural networks have an excellent potential to detect and isolate faults in complex processes. In this paper, an observer based on an adaptive neural network is presented. In this study, the adaptive neural network is designed as an intelligent learning system to detect and isolate sensor and actuator faults in a nonlinear dynamic model of an unmanned aerial vehicle. Due to the** system's **nonlinearity, the neural network's weighting parameters are updated using the extended Kalman filter, which increases the convergence rate of the neural network. A set of abrupt, intermittent and incipient faults are applied to a nonlinear dynamic model of a tilt rotor to evaluate the method. Due to the high update rate of neural network weighting, the proposed method can detect abrupt, intermittent and incipient faults accurately and quickly. Numerical simulation results are also given to show the performance of the proposed method, which shows the proper performance of this design.**

**KEYWORDS**

**Fault detection, Tilt rotor, Adaptive neural network, Extended Kalman filter, nonlinear dynamic**

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## 1. Introduction

In recent years, the quadrotor drone has received much attention as a particular type of drone. Due to the unique capabilities of vertical take-off and landing and hovering, this vehicle has been widely used in many areas, for example, security patrol, forest fire monitoring, search and rescue, power line inspection, remote sensing, geographical studies, recognition and aerial transportation [1]. Integrating unmanned aerial vehicles in urban scenarios requires increased reliability and fault predictability, especially when these unmanned vehicles must be certified to fly in densely populated areas. Considering that faults in aviation systems can cause irreparable financial losses, early detection plays a vital role in the flight control system. Unmanned aerial vehicles (UAVs) are more vulnerable to faults because they need to detect and compensate for faults without a human interface. Fault detection is one of the most critical problems in aerospace engineering. In UAVs, size, weight, and cost are the three critical factors in their design. For these reasons, hardware redundancy is not a tangible solution for designing fault-tolerant systems for small UAVs, which should be lightweight and cost-effective. Therefore, the idea of analytical redundancy has been proposed as an alternative solution. Since the analytical redundancy approach is based on a mathematical model of the system, they are called model-based techniques for fault detection (FD). Actuator and sensor faults are two major faults that should be detected and isolated in UAVs. In actuator malfunction, the control system cannot correctly apply its commands to the system so that the flight performance may degrade. Actuator faults mean partial loss or malfunction of the actuator's control actions. Thus, the actuator fault should be detected first to design an effective fault-tolerant controller. In sensor malfunction, the needed information may not be correctly measured, transmitted or received correctly by the control system; therefore, the control system does not behave appropriately due to the false information. For this reason, sensor failure may cause more severe problems in the UAV control system [2]. In this paper, we have developed a nonlinear model-based fault detection strategy for aircraft sensors and actuators. This strategy includes an adaptive NN in which its learning coefficient is updated by EKF. This strategy includes an adaptive NN, the learning coefficient updated by EKF.

## 2. Tilt rotor dynamic model

To design an accurate fault detection system, an accurate dynamic model is needed; unlike traditional quad-rotor models, which have only four rotatory propellers as the vehicle's inputs, in tilting rotor quadcopters, there are four more servo motors attached to each arm that adds one degree of freedom to each of the propellers, resulting in the tilting motion along their axes. This section presents the equations of motion of a tilting rotor quadcopter. "Figure 1" schematically shows the coordinate system and forces acting on a tilting quadcopter [2].

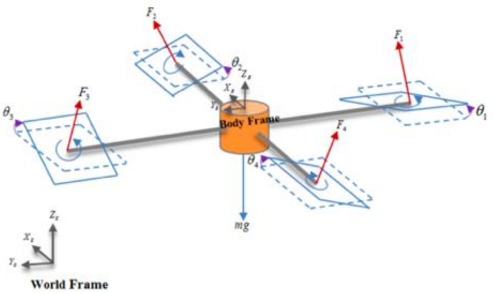


**Figure 1. Schematic diagram showing the coordinate systems and forces acting on the tilting quadcopter**

## 3. Tilting Rotor with One Propeller Failure

When all the propellers of the tilt-rotor quadcopter are working then it yields a stable configuration as a result of symmetry of forces and moments. Without loss of generality, we assume that first propeller/motor which is located in the roll plane fails during hovering flight of the quadcopter. Then, the quadcopter would possess three working propellers and one failed propeller. Once the failure occurs the UAV will experience asymmetry about the roll axis. When all the propellers of the tilt-rotor quadcopter are working, it yields a stable configuration due to the symmetry of forces and moments. However, if the first propeller/motor, located in the roll plane, were to fail during the hovering flight, the quadcopter would be left with three working propellers and one failed propeller. This asymmetry about the roll axis would significantly impact the UAV's stability.

## 4. Neural Network Adaptive Structure

Faults in a system may be nonlinear and unpredictable; hence, an NN can be a suitable candidate for fault estimation. Unlike the direct NN modelling procedures, an NNAS estimates faults based on the nonlinear observer and sensor/actuator output.

### 4.1. Neural network weight update law

In order to have fast fault detection, neural network weights should be tuned [3]. Neural network weights should be tuned to achieve fast fault detection. An adaptive parameter tuning algorithm based on the

Extended Kalman Filter (EKF) is introduced. This filter helps to update the NN weighting parameters online with a fast convergence rate of learning.

## 5. Results and Discussion

This section shows that the proposed scheme is able to detect and isolate the faults of tilt-rotor actuators and sensors. A quadcopter with tilting rotors is chosen as the test bed; detailed specifications are given in reference [4]. The initial conditions of the neural network are selected based on the dynamic of the system and designer objectives. Based on the system's complexity, they can be tuned through manual tuning after a few simulations or using offline optimization algorithms like genetic algorithms [3]. In order to show the advantages of the introduced technique, various simulation scenarios have been tested. The simulation results are presented in "Figure 2-4". Due to the speed of adaptation, the proposed method has high accuracy in fault detection. In order to evaluate the advantages of the proposed strategy over the pure neural network quantitatively, the root-mean-square errors (RMSE) of both detection strategies are calculated. The proposed design has much less RMSE then the conventional pure NN-based detection strategy.

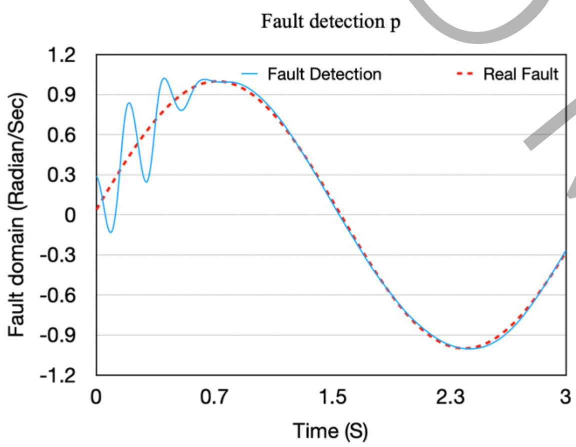


**Figure 2: Ability of proposed method for detect sinusoidal fault in sensor**

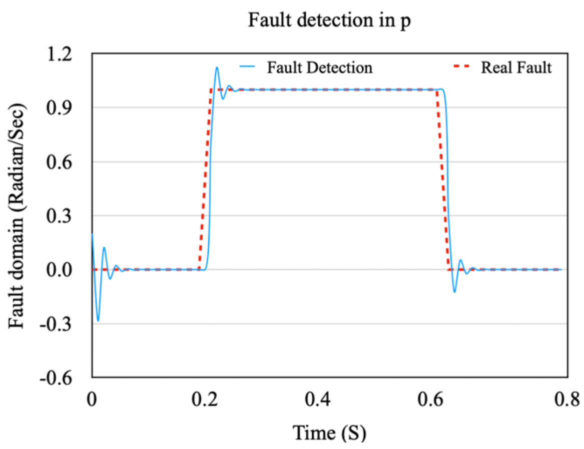


**Figure 3: Ability of proposed method for detect abrupt fault (rectangular) in sensor**

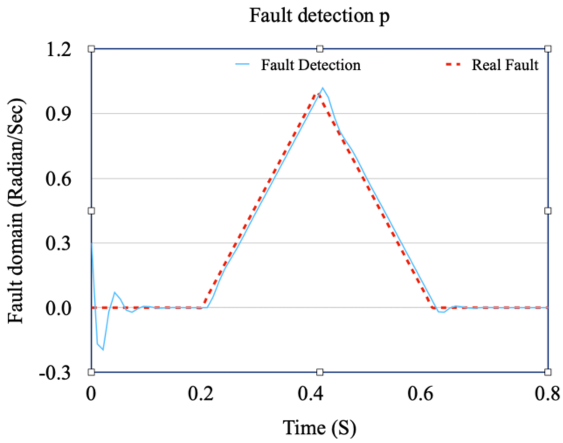


**Figure 4: Ability of proposed method for detect abrupt fault (triangular) in sensor**

## 6. Conclusions

In this paper, a fault detection technique has been introduced. In this technique, a neural network is used for fault detection, while its weighting parameters are updated by an extended Kalman filter. This technique uses a neural network for fault detection while an extended Kalman filter updates its weighting parameters. The root-mean-square error shows that the proposed method can efficiently detect and identify faults in UAV sensors and actuators. Moreover, its ability has been compared with one of the recent neural network-based fault detection methods, and the simulation results show that the proposed method has better performance in detecting faults. This accurate and efficient technique can be used for UAV fault detection to improve safety and reliability, especially when restrictions on their cost and weight are imposed.

## 7. References

[1] H. Lim, J. Park, D. Lee, H.J. Kim, Build Your Own Quadrotor: Open-Source Projects on Unmanned Aerial Vehicles, IEEE Robotics & Automation Magazine, 19(3) (2012) 33-45.

[2] I. Samy, I. Postlethwaite, D.-W. Gu, Survey and application of sensor fault detection and isolation schemes, Control Engineering Practice, 19(7) (2011) 658-674.

[3] A. Abaspour, S.H. Sadati, M. Sadeghi, Nonlinear optimized adaptive trajectory control of helicopter, Control Theory and Technology, 13 (2015) 297-310.

[4] S. Sridhar, G. Gupta, R. Kumar, M. Kumar, K. Cohen, Tilt-Rotor Quadcopter Xplored: Hardware based Dynamics, Smart Sliding Mode Controller, Attitude Hold & Wind Disturbance Scenarios, in: 2019 American Control Conference (ACC), 2019, pp. 2005-2010.