ABSTRACT

Complex control algorithms are essential to the performance, reliability, and safety of contemporary industrial applications. Any fault or malfunction can cause an engineering system to be disrupted, which can lead to decreased or subpar performance, reliability, and safety. To address a variety of faults, new strategies for controlling system have been created, enabling faults to be tolerated while preserving desired stability and performance. Thus, reliable Fault Tolerant Control (FTC) depends on Fault Detection and Diagnosis (FDD).

Today, a variety of military and non-military uses for aerial vehicles exist, including border control, monitoring, surveillance, geological mapping, firefighting, search and rescue, transportation, and environmental research. A well-known type of airborne rotorcraft is the highly manoeuvrable conventional helicopter system. Helicopter accidents are more common than those involving fixed-wing aircraft due to structural characteristics, complicated systems, ambient factors, and non-linear aerodynamics. Therefore, there are several difficulties involved in flight control, which affect performance and stability. Faults in control actuators, sensors, and system components are among the factors causing these accidents. As a result, maintaining appropriate performance while assuring safety requires helicopter fault detection and control.

The purpose of this work is to investigate the design of fault diagnosis and control for helicopters. Fault detection and control of non-linear helicopter systems is crucial in ensuring safety and reliability. The effects of faults on system dynamics become more challenging to control due to the complexity of helicopter dynamics, which exhibit significant non-linearity and cross-coupling

as well as external disturbances like wind, icing, and air turbulence that affect the system. As a result, the goal of this work is to provide an active fault diagnosis and control approach for a non-linear two-degrees-of-freedom helicopter system when it is exposed to different abnormalities, such as sensor, actuator, and component faults.

Observers is one of many model-based fault diagnosis (FDD) methods that have been reported in the literature. A non-linear observer called the sliding mode observer enables reliable residual generation that makes it possible to identify faults. On the basis of the actual and predicted system states, residual are generated. By employing a Lyapunov-based method to determine observer gain, the system's stability is also ensured. Results indicate that the estimated states closely follow the system's actual states. The presence of faults in the system is determined from the error residuals. The drawback is that residual information is insufficient for fault classification. Additionally, incorrect observer gain and a variety of disturbances cause the observer estimate to diverge, which results in a false residual indication.

Multiple model-based (MM) fault diagnostics has the core advantage of being able to depict a wider range of faults. This makes it possible to simulate sensor, actuator, and component faults because local fault models have the ability to reflect different dynamics. A collection of models interact with one another to enhance fault detection in the Interacting Multiple Model (IMM) filter. In conventional IMM filters, system states and covariance are propagated via the Kalman Filter (KF). The Extended Kalman Filter (EKF) and the Unscented Kalman Filter (UKF) were developed to address non-linear systems because the Kalman filter is only useful for linear systems. The sensor, actuator, and component faults arising in the non-linear helicopter model are thus addressed by an IMM-EKF and IMM-UKF. While fault categorization is based on mode probability, fault detection is based on generated residuals and likelihood ratio. For non-linear systems with gaussian noise, this FDD approach is used. Results reveal that while IMM-EKF tracks the system states with some offset, IMM-UKF tracks them precisely. Additionally, IMM-UKF diagnoses faults more accurately than IMM-EKF. Due to the offset created while recording the system states, IMM-EKF is unable to provide accurate fault detection.

High levels of non-linearity and undesirable non-gaussian noise effects are present in helicopter systems. As a result, a sequential Monte Carlo technique called the Particle Filter (PF), which is based on Bayesian theory, is designed to address the issue. In particle filter-based FDD, faulty models that depict systems with faults and normal models that reflect systems without faults are taken into consideration. Hypothesis testing is a common technique for keeping track of parametric changes in a system. The hypothesis is computed using Log-Likelihood Ratio (LLR), which is then used to test the hypothesis. Using the states predicted by the particle filter, the likelihood function for the normal and faulty models is assessed to determine LLR. The calculated LLR is compared to the threshold value to produce a fault decision signal. A dynamic threshold value is calculated using the standard deviation of the likelihood of the normal model to arrive at an ideal threshold value. Results demonstrate that the log-likelihood ratio approach of fault identification exhibits superior fault detection than the residuals. A decision signal indicating the presence of fault is generated for two separate threshold values once a fault has been detected. In comparison to the normal threshold value, the fault decision signal computed from the dynamic threshold value produces better results.

A controller must be designed as soon as a fault is discovered in order to guarantee safety and deliver acceptable performance. Therefore, a fault tolerant control is built to withstand system faults. Sliding Mode Control (SMC), which is effective in addressing uncertainties, is designed because helicopters are vulnerable to disturbance and uncertainty. This work designs discontinuous control utilising the basic reaching lawand the super-twisting control. The main drawback of reaching law is the chattering issue, which causes minute fluctuations in the controller signal. A second order sliding mode control called super-twisting control is created to lessen chattering. Supertwisting SMC requires less control effort than reaching law SMC to follow the set point.

It is challenging to maintain the same acceptable performance in the presence of non-linearity and uncertainty, even while acceptable performance is guaranteed with fault diagnosis and fault tolerant control operating separately. An integrated design of fault diagnostic and fault tolerant control is proposed to increase system reliability and achieve desired control performance. With adaptive sliding mode control, the control rule is modified to enhance dynamic properties as the system's parameters change. Due to the fact that gain is correlated with chattering amplitude, the adaptive law is intended to change the gain of discontinuous control. Based on state feedback from the particle filter estimation, the controller is created. The control gain is calculated as the difference between the system states and the discontinuity surface. System state and error covariance are both used by the controller as state feedback. Since likelihood is determined by the difference between the actual state and the estimated state, co-variance can be connected to the likelihood function of the particle filter. Therefore, to improve performance with less chattering, the controller gain is dynamically adjusted using the likelihood function. Various performance metrics are analysed to show the effectiveness of SMC algorithms. The results indicate the SMC tuned from PF tracks the system states perfectly. Also, performance metrics shows slight improvement in performance than supertwisting SMC. Also a stability analysis is carried out using Lyapunov approach in the face of faults and the stability of the controller is guaranteed.