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Sensor Installation for Data Fusion for Detecting UAV Control Surface Fault

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Abstract: System redundancy in aircraft is very important as it ensures faulty components would not jeopardize the safety of crew and passengers. High priority system such as flight control computers, instruments system and controller for control surface mechanism have double or triple redundancy to maintain the aircraft safety. While full scale aircraft has multiple redundancy system installed, small unmanned aerial vehicle on the other hand do not have these system installed due to cost and weight. Propulsion, either fuel or electric powered and control surface movement are prone to damage due to wear and tear of mechanical movement. Severe damage could occur if the UAV lost control of its control surface. Elevator system fault would result in the most severe as it controls the vertical movement of the UAV. This research presents the initial development of a fault recovery system by changing the pitching movement control by the elevator to stabilator control. This paper in particular would discuss the approach to construct the sensor system for detecting and identifying the fault of control surface of small UAV during the flight. Servo fault detection would be used as the basis of providing suitable recovery scheme. Fast detection and recovery with light weight system are the main parameters that are considered during evaluation and development stage. The outputs of these sensors in normal and abnormal condition of elevator have been determined for the development of fault detection and identification scheme.

Keywords— Unmanned Aerial Vehicle, Fault Detection, Servo Fault, Fault Recovery.

I. Introduction

Unmanned Aerial Vehicle (UAV) is being used in the fields of research and civilian application. For military, it provides valuable visual and intelligence information that can be lifesaving. However, UAV commercial usage by civilian is not yet as mature due to some issues regarding regulation and safety that needs to be addressed before it can be widely accepted. As mentioned by [1] reliability, maintainability and survivability of unmanned systems have been the issue of many researches over the last decades. Using conventional feedback from the autopilot would not be able to stabilized the UAV in case of control surface failure [2].

The fault of the UAV can be categorized into fault of propulsion, data link or Flight Control Systems [3]. For example, after an actuator fails, the performance of an aircraft is degraded [4]. If a fault detection and isolation system is available, the information of the failure can be used to re-evaluate the UAV's flying characteristics. Later, a supervision system decides whether the UAV can proceed with the mission or land immediately in safe maneuver. In both cases, the UAV would still be flying, but under new flying properties with sufficient level of performance to ensure security of the UAV and its payload under the fault state [5].

Hajiyev and Soken in their study used Robust Adaptive Kalman Filter (RAKF) to provide accurate estimation of sensor or actuator failure. In a single algorithm, the Robust Adaptive Kalman Filter detects the fault, isolates it and applies the required adaptation process such that the estimation characteristic is not deteriorated [6]. On the other hand, Baoanet Al. used UAV flight attitude to achieve track forecast, and the established state-space equation by using particle filters which are sequential Monte Carlo methods based on point mass [7]. Unscented Kalman Filter (UKF) is employed by J. Qi et al. [8] to model the actuator failure to denote the actuator healthy level (AHL) for on-line estimation of both the flight states and the actuator healthy level parameters of UAV.

By using nonlinear UAV model, Samy et al.used Model-based sensor fault detection, isolation accommodation (SFDIA). It is used for UAVs where sensor redundancy may not be an option due to weight, cost and space limitation which simulated many sensor faults between consecutive faults [9]. Another nonlinear aircraft model designed for Fault Tolerant Control Strategy research has been proposed where diagnosis system is designed with a bank of unknown input decoupled functional observers (UIDFO) which is able to estimate unknown inputs. It is coupled with an active diagnosis method in order to isolate the faulty control [10].

Another method used by Fan et al. [11] is by using a set invariance condition for a piecewise continuous time-varying system. The system is developed and applied to the fault-tolerant control problem against the actuator effectiveness loss for linear systems subject to system uncertainties and actuator saturation.

II. Problem Statement

In full scale, manned piloted aircraft, redundancy of software and hardware can be implemented without affecting much of its weight. However, the same redundancy system must be thoroughly designed as adding additional weight would either reduce the flight endurance or reduce the maneuverability of the UAV.

To add values to the UAV, it must be able to carry various type of payloads such as visual and environmental sensors, which are sometimes much more expensive than the UAV system itself. Thus, the vehicle that transports these sensors must provide guarantee that the payload can be secured in the event of emergency. One of the failures that can occur during mission is the faulty control mechanism for the control surface. Thus, this research work focused on the detection and recovery of the faulty control mechanism for the control surface to safeguard the vehicle and its payload.

II. Material and Methodology

In this research, a normally inactive, redundancy system is implemented using two different pitch control surfaces which are elevator and stabilator. The stabilator will take over control of the elevator when fault is identified and isolated.

Figure 1 shows the control surface of a typical small UAV. Faulty elevator control system can be divided into 3 categories; first is actuator failure which the servo motor stuck due to mechanical failure, the second is linkage failure which cause the linkages to be disconnected from the servo to the control surface, and the third is control surface failure.

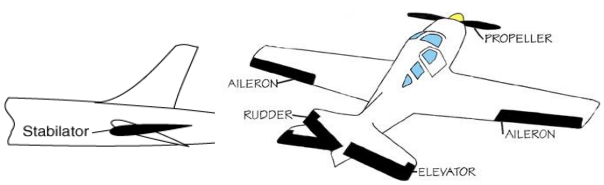

Figure 1: Stabilator and Elevator Control Surface

The most probable cause out of the 3 failures is the actuator failure due to the fact that servo actuator constantly moves to control the stability of the aircraft. Flight control and autonomous navigation is provided by navigation controller while the fault detection system functions as a supervisory system monitoring the faulty elevator and takes over control during emergency.

The fault detection system is composed of elevator position sensors to detect the position of the elevator as commanded by the flight controller. Actual position is detected by two methods; one by flex sensor embedded into the elevator hinge and the other one is position sensor by using potentiometer at the servo spline. Output from the positional sensor will be constantly measured by the system. Thus, when the output does not correspond to the input commands from the flight controller and it has been identified as faulty, an alternate control system will take over to accommodate and to restore the flight stability.

From the system assessment of the fault condition, the UAV will be able to proceed with the mission, or abort the mission by safely returning to an appointed location. A simple summary on the control system is shown in Figure 2.

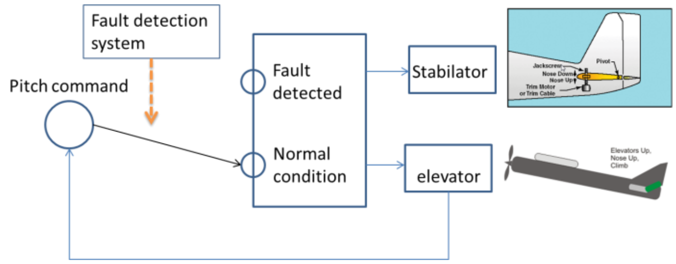

Figure 2: Simplified Diagram of Fault Detection, Isolation and Recovery System

Actual output of the actuators are measured and compared to the input from the flight controller where the fault detection will decide on the necessary deflection angle of the stabilator.

The controller is used to read elevator positional sensor signal and input command from autopilot system. The sensors selected are analog sensors. Flex sensor is used to measure the deflection angle of the elevator while analog potentiometer is attached to the servo output to measure the rotational movement of the servo output. These sensors were selected due to their small size and light weight. Since the output from the autopilot to the servo is in the form of digital PPM signal, these data needs to be sent to the controller board as reference signal. Figure 3 shows the arrangement of the analog flex position detection sensor and positional sensor from servo actuator.

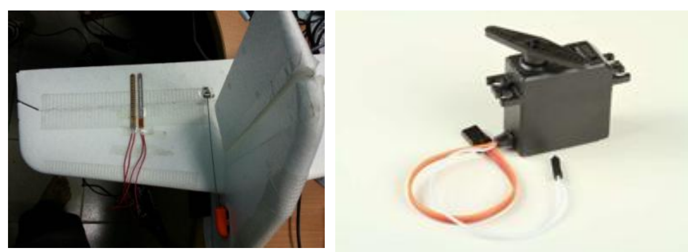

Figure 3: Arrangement of the Flex Sensor and Positional Sensor Installed Inside Servo Actuator

III. Results and Tables

Two flex sensors mounted back to back were used to detect the movement from the elevator as the sensor is only sensitive to bending in only one direction. Figure 4 shows test data of the two sensors, series Flex 1 and Flex 2. The PPM line shows the command signal from simulated input to the servo. Further signal conditioning is needed so that the full travel of the elevator would use the maximum range of the 10-bit ADC converter built inside the controller.

Initially, the command signal is sent in triangular shape. Then, step signal for elevator maximum up and maximum down are sent followed by the final signal which is to move the servo to its neutral position. Flex 1 data is sensitive to down deflection of the elevator, while Flex 2 data is sensitive to up deflection of the elevator. Both data is normalized in order to achieve the same data in neutral position of the elevators.

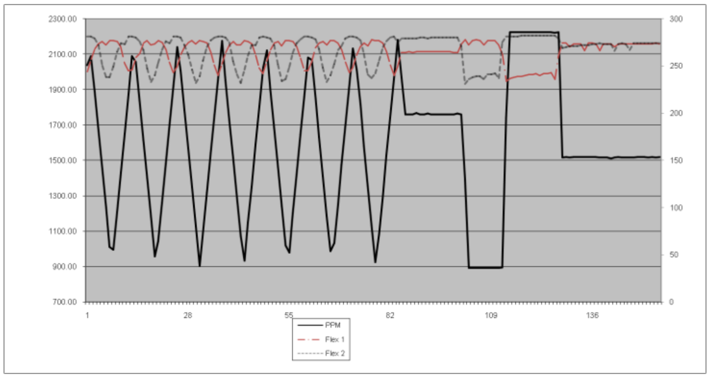

Figure 4: Data Showing 2 Stacked Flex Sensors with PPM Signal Input.

Figure 5 shows the data collected from the positional sensor installed. The PPM values range from 1000 to 2000 and the corresponding Analog to Digital converter from the microcontroller input.

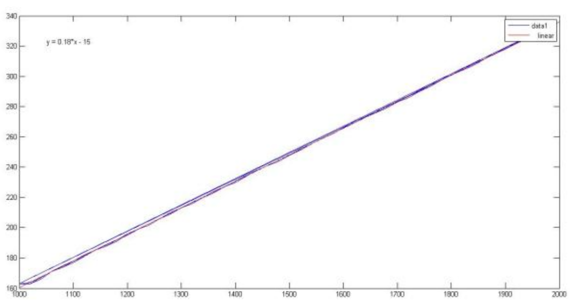

Figure 5: Data Regression for the ADC and PPM

IV. Conclusion

The development of the fault detection system starts with the selection of appropriate sensor for detection. Simulated data from sensors showing correlation between input signal and output movement of the servo. However, the deflection angle data needs to be further processed so that it can shows the movement of the elevator in degree. As the system will be implemented in small size UAV, low weight and efficient processing of data collected is vital in implementing the fault detection system. Data collected in real-time during flight will be used for correlation between normal condition and abnormal condition. Signal analysis for the decision making to recover the loss of effective control of the elevator will be implemented in future work.

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