Discussion on: “FDI Using Multiple Parity Vectors for Redundant Inertial Sensors”

C.W. Chan

Department of Mechanical Engineering, The University of Hong Kong, Pokfulam Road, Hong Kong, China

In this paper, a fault detection and isolation technique based on the average of the parity vectors is presented. The parity vector sensitive only to specific faults is obtained first using existing methods [1,2]. A fault detection function defined as the average of $q$ parity vectors obtained in previous time periods is then computed. Faulty sensors are accommodated or included in the estimation of the triad positions in the inertial navigation system (INS) if this function is less than a certain threshold. The main advantage of the proposed method is that it reduces the probability of false alarms and wrong isolations, and at the same time increases the probability of correct isolation, as more measurements are used in the estimating the triad positions. The accommodation threshold for fault detection is also derived based on the variance of the measurement noise of the sensors. The implementation and performance of the method are illustrated using simulation and experiments.

It should be noted that the concept of fault accommodation introduced by the authors has a unique meaning. In the paper, fault accommodation is interpreted as whether or not to include a faulty sensor in the estimation of the triad positions of the INS, whilst other authors [3,4] are concerned also with the compensation of faults in faulty sensors in order to minimize their effect on the estimation of the triad positions.

Another interesting result presented in the paper is that the triad positions of the INS, $\hat{x}(t_k)$, obtained including faulty sensors having faults with a magnitude less than the accommodation threshold is more accurate than that obtained by excluding them. This inference comes from the result that the variance of the estimated triad positions, $\hat{x}(t_k)$, including the faulty sensors is smaller than that obtained without them. However, it should be noted that $\hat{x}(t_k)$ obtained by including faulty sensors has a bias of $(H^TH)^{-1}H^TV_{Pi}f(t_k)$, as given by (7) in the paper, whilst $\hat{x}(t_k)$ obtained without the faulty sensors is an unbiased of $x(t_k)$. As this bias may be undesirable if $\hat{x}(t_k)$ is used, for example, to compute the closed-loop control, a fair comparison between a technique using the faulty sensors and the other not using them needs to take this bias into account.

1. Main Result

The main contribution of the paper is the proposal to detect faulty sensors using the fault indication function, $\hat{f}_i(t_k)$, obtained by averaging $q$ consecutive parity vectors, $\{p(t_k - i), \text{ for } i = 0, \ldots, q - 1\}$. The threshold $Th_E$ for accommodating or including faulty sensors as given in Theorem 1 is,

$$Th_E = \frac{\sigma}{\|v_i\|}$$  \hspace{1cm} (1)

It is proposed that if $\hat{f}_i(t_k)$ is less than $Th_E$, then the faulty sensors can be accommodated in the estimation of $\hat{x}(t_k)$, since the variance of the estimate of the triad positions including them is smaller. The authors discuss also the probability of the false alarm, and present some results based on Monte Carlo simulation, as closed form solution is difficult to obtain.
The approach proposed by Zhang, et al [5] based on the local asymptotic approach also involves a statistic that is the average of the residuals derived for fault detection. To reformulate the fault accommodation technique presented in the paper using the local asymptotic approach, define first the following statistic $S(t_k)$,

$$S(t_k) = D^2(t_k)$$

where $D(t_k) = \hat{f}(t_k)/\sigma$. Consider the hypothesis test [4,5],

$$H_0 : D(t_k) < \frac{\sigma}{\sqrt{q||v_i||}}, \quad H_1 : D(t_k) \geq \frac{\sigma}{\sqrt{q||v_i||}}$$

The hypothesis $H_0$ expresses that the sensor fault is less than $T_{HE}$ given by (1), whilst hypothesis $H_1$ corresponds to one that is greater than $T_{HE}$. Since $S(t_k)$ is $\chi^2$ distributed with one degree of freedom, the hypothesis test for accepting the hypothesis $H_0$ can be decided by the $\chi^2$ test at a specific confidence level. The advantage of this approach is that the probability framework for including or excluding the faulty sensors can be readily derived. A discussion on the guidelines for choosing $q$ using the local asymptotic approach can be found in [6].

The reader may also like to note the typing errors in the subscripts of (15) and also subsequent equations involving similar subscripts. In these equations, the subscripts $t_{l-q-1}$ and $t_{l-q+1}$ should be read as $t_{l-q}$ and $t_{l-q+2}$ respectively.

2. Simulation and Experimental Results

An important contribution of the paper is that the experimental results presented provide a useful confirmation of the results obtained from simulations, and thus help the reader to better understand the implementation and performance of the proposed method.

References