SAFEPROCESS2000
PERGAMON
ISBN: 0-08-043250-6
Vol II, 379-384pp

FAULT DETECTION AND ISOLATION FILTER DESIGN BY INVERSION: THE CASE OF LINEAR SYSTEMS

Ferenc Szigeti *, **Addison Ríos** *, **Rocco Tarantino** **

* *Universidad de los Andes, Facultad de Ingeniería, Departamento de Control, Mérida 5101, Venezuela,*
szigeti@ing.ula.ve, ilich@ing.ula.ve
** *CRP Cardón, PDVSA Refinería Cardón, Po.Box: 1516 de la Comunidad Cardón, Punto Fijo, Falcón, 4102, Venezuela,*
roccot@telcel.net.ve

Abstract: This article proposes a new filter design method fault detection and isolation. The method is based-on two necessary conditions: the first condition is a weak failure observability and the another is a weak failure separability condition. If the two conditons are satisfied, we can design the filter via Luenberger's observers and one dynamic post-filter. The post-filter is designing by a inverse dynamical. In this method, the (C, A)-invariance is completely ignored.

Keywords: Fault detection and isolation, Weak failure observability, Weak failure separability, Luenberger's observer, System inversion.

1. INTRODUCTION

The design of a fault detection and isolation (FDI) filter based-on Luenberger's observer has a well-known algebraic (geometric) obstacle. The fault signatures must be output separable, see (Massoumnia 1986). That is, the minimal $C - A$ invariant subspaces generated by the fault signatures must be linearly independent in the output space under the action of the output mapping C. The difficulty is of algebraic nature; counterexample shows that the minimal $C - A$ invariant subspace generated by only one vector may be the whole state space, hence the diagnostic system has no chance for output separability.

Our earlier efforts in papers (Edelmayer *et al.* 1997*b*, Edelmayer *et al.* 1997*a*), and (Keviczky *et al.* 1992) was motivated by a possible generalization of the synthesis of fault detection filters to time varying linear systems. Our expectations were based on a purely geometric description of the observability and reachability subspaces of the time varying linear systems, see (Szigeti 1992, Szigeti *et al.* 1995). The first approach was the replacement of the time varying diagnostic system by a time invariant one, that is equivalent in a certain sense, to the original system. Then classical results were applied to the equivalent time invariant system.

However, in the time invariant diagnostic system, equivalent to the time varying one, the dimension of the failure signatures has increased sensitively affecting the output separability of the diagnostic system. Therefore, the generalized observers were proposed for state reconstruction, estimation in (Szigeti *et al.* 1997*b*) and (Szigeti *et al.* 1997*a*). The novelty of those observers was the injection of the output derivatives. Hence the error dynamics was split for the unobservable and the observable part with the assigment of the observable dynamics. From that, analogous results to the well-known stabilization and detection were obtained for time varying and bilinear systems.

The synthesis of fault detection filters, however, has seemed a hard problem using generalized observers in consequence of the appearance of the failure terms in the output. Nevertheless, the fault detection problem were treated by this way for several practical problems, see (Szigeti and Tarantino 1998).

Recently, Patton *et al.*, (Patton and Hou 1997), presented an interesting a very nice paper on fault observability and reconstructability for dynamic systems. The proposed input estimator also involves the output derivatives. Analogous results to observability and reconstructability are proven for faults, confirming the usefulness of the output derivative injections.

2. PROPOSITION FOR FAULT ISOLATION BY INVERSION

In our paper a new design method is presented for fault detection and isolation. The diagnostic model is supposed to be time invariant and linear. In this case classical Luenberger's observers can also be used.

The considered diagnostic model is

$$\dot{x}(t) = Ax(t) + Bu(t) + \sum_{i=1}^{J} L_i v_i, \tag{1}$$

$$y(t) = Cx(t), \tag{2}$$

where $A \in \Re^{n\times n}$, $B \in \Re^{n\times p}$, $C \in \Re^{q\times n}$, and $L_i \in \Re^{n\times p_i}$.

Now, we introduce a particular system with inputs and outputs of the same dimension:

$$\left.\begin{array}{rcl} \dot{x}_1 &=& -x_1 + u \\ \dot{x}_2 &=& x_1 - x_2 \\ \cdots && \\ \dot{x}_k &=& x_{k-1} - x_k \end{array}\right\} \tag{3}$$

$$y = \sum_{i=1}^{k} C_i x_i, \tag{4}$$

where $x_1, \cdots, x_k, u, y \in \Re^p$, $C_i \in \Re$, for some i, $C_i \neq 0$. The transfer function of systems (3), (4) is

$$H(s) = \sum_{i=1}^{k} \frac{C_i}{(s+1)^i}. \tag{5}$$

If the function $u : [0, \infty) \longrightarrow \Re^p$ is zero for $t \leq t_0$ and $x(0) = \left(x_1(0)^T, \cdots, x_k(0)^T\right)^T = 0$, then the response $y(t)$ is also zero for $t \leq t_0$. Supposing that u is piecewise continuous and that $u(t) \neq 0$ in a right neighborhood $(t_0, t_0 + \epsilon)$ for any $\epsilon > 0$, then $y(t)$ is not identically zero at the same neighborhood. This property justifies that system (3), (4) is called a detector for u. Roughly speaking, if u is trigged at the moment t_0, then also y is trigged at the same t_0.

Let us suppose that diagnostic model (1), (2) is detectable. Denoting the orthogonal projection onto the observable subspace

$$\mathcal{O} = \sum_{i=1}^{n-1} Im\ (A^{*i} C^*),$$

by P, $P : \Re^n \longrightarrow \Re^n$, $Im\ P = \mathcal{O}$. We say that the ith failure signature is weakly observable if

$$\text{Ker}(PL_i) = 0 \tag{6}$$

It is obvious that, the weak failure observability of the ith failure is necessary to its observability, see (Hou and Patton Submitted) or (Patton and Hou 1997) for failure observability, since if $\text{Ker}(PL_i) \neq 0$, then a fault signal $v_i(t) \neq 0$ can be hidden in the $\text{Ker}(PL_i)$.

The diagnostic model (1), (2) is weakly separable from the other failure signature if

$$Im(PL_i) \bigcap \sum_{\substack{j=1 \\ j\neq i}}^{J} Im(PL_i) = 0 \tag{7}$$

It is obvious that weak failure separability of the ith failure signature is necessary to failure separability, since if a non zero fault signal $PL_i v_i(t)$ belongs to the non-zero intersection (7), then $PL_i v_i(t)$ can be decomposed by

$$0 \neq PL_i v_i(t) = \sum_{\substack{j=1 \\ j\neq i}}^{J} PL_j v_j(t),$$

and, obviously, failure L_i can not be isolated from failures L_j, satisfying $PL_j v_j(t) \neq 0$.

The diagnostic model (1), (2) is weakly failure separable if all failure signature are weakly separable from the other failure signatures.

Now, we are able to formulate the main result of the paper:

Theorem 1. Let us suppose that diagnostic model (1), (2) is detectable, weakly failure observable and weakly failure separable. Then, if $\sum_{i=1}^{I} p_i \leq q$ (where q represent the available outputs) there exists a Luenberger's observer of gain matrix D, with the corresponding error equation

$$\dot{e}(t) = (A - DC)e(t) + \sum_{i=1}^{J} L_i v_i, \tag{8}$$

$$\eta(t) = Ce(t), \tag{9}$$

and a dynamical filter

$$\dot{z}(t) = Fz(t) + G\eta(t), \tag{10}$$

$$\left.\begin{array}{rcl} w_1(t) & = & K_1 z(t), \\ & \cdots & \\ w_J(t) & = & K_J z(t), \end{array}\right\}, \tag{11}$$

such that (10) is asymptotically stable and the system

$$\dot{e}(t) = (A - DC)e(t) + L_i v_i, \tag{12}$$

$$\dot{z}(t) = Fz(t) + GCe(t), \tag{13}$$

$$w_i(t) = K_i z(t) \tag{14}$$

is a detector of v_i, for $i = 1, 2, \cdots, J$.

Theorem 1 says that under necessary conditions for the diagnostic systems, failures can be decoupled in detectors. The Fig. 1 shows the schematic diagram of the detector proposed.

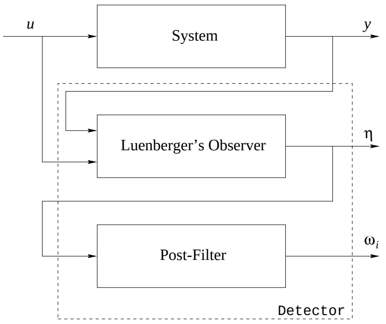

Fig. 1. Schematic diagram for the FDI filter.

In this method, the unique inconvenience of the stated is, that $w_i(t)$ are detected instead of the system failures. If the order of the detector, the number k of the blocks of detector (3), (4), is high, then the output signal $w_i(t)$ is flat. The fault detection of a noisy system from flat output signal can be hard.

PROOF. First, let us split $\Re^n$ in the orthogonal sum

$$\Re = \mathcal{O} \oplus U,$$

where U is the unobservable subspace. Let system (1), (2) be realized over $\mathcal{O}$ in the observable canonical form:

$$\dot{x}(t) = \left(\begin{array}{ccc|c} \mathrm{A}_{11} & & & \\ & \ddots & & 0 \\ & & \mathrm{A}_{qq} & \\ \hline & A_{U\mathcal{O}} & & A_{UU} \end{array}\right) x(t) + Bu(t) + \\ + \sum_{i=1}^{J} L_i v_i(t),$$

$$y(t) = \left(\begin{array}{ccccccc|c} 0 & \cdots & 1 & \cdots & & \cdots & 0 & \\ & & & 0 & \cdots & 1 & & \\ & & & & & \ddots & & 0 \\ 0 & & & \cdots & & 0 & \cdots\ 1 & \end{array}\right) x(t);$$

where

$$\mathrm{A}_{11} = \begin{pmatrix} 0 & \cdots & \cdots & a_{10} \\ 1 & & & \vdots \\ & \ddots & & \vdots \\ 0 & & 1 & a_{1n_1-1} \end{pmatrix},$$

and

$$\mathrm{A}_{qq} = \begin{pmatrix} 0 & \cdots & \cdots & a_{q0} \\ 1 & & & \vdots \\ & \ddots & & \vdots \\ 0 & & 1 & a_{qn_q-1} \end{pmatrix}.$$

The assumption on detectability of (1), (2) means that the unobservable system

$$\dot{x}_U(t) = A_{UU} x_U(t)$$

is asymptotically stable. Therefore, there exists an asymptotically stable Luenberger's observer

$$\dot{\hat{x}}(t) = A\hat{x}(t) + Bu(t) + D(y(t) - C\hat{x}(t)), \tag{15}$$

$$\hat{y}(t) = C\hat{x}(t), \tag{16}$$

with the corresponding error equation

$$\dot{e}(t) = \left(\begin{array}{ccc|c} \mathrm{A}_{d_1} & & & \\ & \ddots & & 0 \\ & & \mathrm{A}_{d_q} & \\ \hline & A_{U\mathcal{O}} & & A_{UU} \end{array}\right) e(t) + \sum_{i=1}^{J} L_i v_i(t),$$

$$\eta(t) = \left(\begin{array}{ccccccc|c} 0 & \cdots & 1 & \cdots & & \cdots & 0 & \\ & & & 0 & \cdots & 1 & & \\ & & & & & \ddots & & 0 \\ 0 & & & \cdots & & 0 & \cdots\ 1 & \end{array}\right) e(t);$$

with

$$\mathrm{A}_{d_1} = \begin{pmatrix} 0 & \cdots & \cdots & a_{10} - d_{10} \\ 1 & & & \vdots \\ & \ddots & & \vdots \\ 0 & & 1 & a_{1n_1-1} - d_{1n_1-1} \end{pmatrix},$$

and

$$\mathrm{A}_{d_q} = \begin{pmatrix} 0 & \cdots & \cdots & a_{q0} - d_{q0} \\ 1 & & & \vdots \\ & \ddots & & \vdots \\ 0 & & 1 & a_{qn_q-1} - d_{qn_q-1} \end{pmatrix}.$$

Let us denote the new systems parameters by $\alpha_{ij} = a_{ij} - d_{ij}$, $i = 1, \ldots, q$, $j = 0, 1, \ldots, n_{i-1}$.

Then, asymptotic stability of observer (15), (16) means that

$$p_1(s) = s^{n_1} - \alpha_{1n_1-1}s^{n_1-1} - \cdots - \alpha_{10}$$
$$\vdots$$
$$p_q(s) = s^{n_q} - \alpha_{qn_q-1}s^{n_q-1} - \cdots - \alpha_{q0}$$

are Hurwitz polynomials. Detectability means that the $\mathrm{Det}(sI - A_{UU})$ is also Hurwitz polynomial.

A standard computation shows that the matrix $G(s) = C(sI - A + DC)^{-1}$ is equal to

$$G(s) = \left(G_1(s) \middle| G_2(s) \middle| \cdots \middle| G_q(s) \middle| \; 0 \right);$$

where

$$G_1(s) = \begin{pmatrix} \frac{1}{p_1(s)} & \frac{s}{p_1(s)} & \cdots & \frac{s^{n_1-1}}{p_1(s)} \\ 0 & \cdots & \cdots & 0 \\ \\ 0 & \cdots & \cdots & 0 \end{pmatrix},$$

$$G_2(s) = \begin{pmatrix} 0 & \cdots & 0 \\ \frac{1}{p_2(s)} & \cdots & \frac{s^{n_2-1}}{p_2(s)} \\ \\ 0 & \cdots & 0 \end{pmatrix},$$

and

$$G_q(s) = \begin{pmatrix} 0 & \cdots & 0 \\ \\ 0 & \cdots & 0 \\ \frac{1}{p_q(s)} & \cdots & \frac{s^{n_q-1}}{p_q(s)} \end{pmatrix}.$$

By the weak failure observability, in fact, we can suppose that $PL_i = L_i$, ignoring the unobservable components of L_i, for $i = 1, 2, \ldots, J$.

Then, the transfer function

$$G(s)L_i = \begin{pmatrix} GL_1(s) & \cdots & GL_{1_p}(s) \\ GL_2(s) & \cdots & \cdots \\ \vdots & \vdots & \vdots \\ GL_q(s) & \cdots & GL_{q_p}(s) \end{pmatrix},$$

with $i = 1, 2, \ldots, J$ and

$$GL_1(s) = \frac{1}{p_1(s)} \sum_{j=0}^{n_1-1} L_{i,j+1,1}s^j,$$

$$GL_2(s) = \frac{1}{p_2(s)} \sum_{j=0}^{n_2-1} L_{i,n_1+j+1,1}s^j,$$

$$\vdots$$

$$GL_q(s) = \frac{1}{p_q(s)} \sum_{j=0}^{n_q-1} L_{i,n_1+\cdots+n_{q-1}j+1,1}s^j,$$

$$GL_{1_p} = \frac{1}{p_1(s)} \sum_{j=0}^{n_1-1} L_{i,j+1,p_i}s^j,$$

$$\vdots$$

$$GL_{q_p}(s) = \frac{1}{p_q(s)} \sum_{j=0}^{n_q-1} L_{i,n_1+\cdots+n_{q-1}j+1,p_i}s^j.$$

The transfer function $G(s)L$, with $L = (L_1 \ldots L_J)$ is of full rank, in consideration of the assumption $\sum_{i=1}^{J} p_i \leq q$, that is, if a combination of the columns of $G(s)L$ is zero, then the linear combination is trivial.

Let

$$\lambda = (\lambda_{11} \cdots \lambda_{1p_1}, \lambda_{21} \cdots \lambda_{2p_2}, \lambda_{J1} \cdots \lambda_{Jp_J})$$

$$0 = \sum_{i=1}^{J} \sum_{l=1}^{p_i} \frac{\lambda_{il}}{p_k(s)} \sum_{j=0}^{n_k-1} L_{i,n_1+\cdots+n_{k-1}+j+1,l}s^j =$$
$$= \frac{1}{p_k(s)} \sum_{j=0}^{n_k-1} s^j \left(\sum_{i=1}^{J} \sum_{l=1}^{p_i} \lambda_{il} L_{i,n_1+\cdots+n_{k-1}+j+1,l} \right)$$

for all $k = 1, 2, \ldots, q$, $j = 0, 1, \ldots, n_k - 1$, that is

$$\sum_{i=1}^{J} \sum_{l=1}^{p_i} \lambda_{il} L_{i,m,l} = 0$$

for all $m = 1, 2, \ldots, n_1 + \cdots + n_k$.

This latter means that the linear combinations of the column vectors of the matrix $L = (L - 1 \cdots L_J)$, by the constants λ_{il}, is equal to zero. By our assumptions on the weak fault observability and the weak fault separability of the diagnostic system the columns are linearly independent since all λ_{il} are zero; this latter means that the transfer function $G(s)L$ is of full rank.

Hence there exists a full rank matrix $E \in \Re^{(\sum p_i) \times q}$, such that the transfer matrix

$$H(s) = EG(s)L$$

is invertible. Then, denoting $v = \left(v_1^T, \ldots, v_J^T\right)^T$,

$$\begin{aligned} v(s) &= H(s)^{-1}EG(s)Lv(s) \\ &= H(s)^{-1}E\eta(s) \end{aligned} \tag{17}$$

is an input reconstruction.

Unfortunately, $H(s)^{-1}E$ is not a proper matrix in general and may also have unstable poles in $\beta_1, \ldots, \beta_r$ and infinity (unproperness) with multiplicities $m_1, \ldots, m_r, m_\infty$, respectively. Rewritting (17) by components

$$\begin{pmatrix} v_1 \\ \vdots \\ v_J \end{pmatrix} = H^{-1}(s)E\eta = \begin{pmatrix} G_1(s) \\ \vdots \\ G_J(s) \end{pmatrix} \eta,$$

and then multiplying by the proper scalar fraction

$$\frac{p(s)}{(1+s)^k} = \frac{\Pi(s-\beta_i)^{m_i}}{(1+s)^{m_i}} \frac{1}{(1+s)^{m_\infty}}, \quad (18)$$

the following equations are obtained

$$w_i(s) = \frac{p(s)}{(1+s)^k} v_i(s) = \frac{p(s)}{(1+s)^k} G_i(s)\eta(s).$$

The transfer function

$$\tilde{G}(s) = \frac{p(s)}{(1+s)^k} \begin{pmatrix} G_1(s) \\ \vdots \\ G_J(s) \end{pmatrix}$$

is proper and stable. Let us realize by the state model (10), (11). Then, obviously, the statements of Theorem 1 are satisfied.

We notice that if instead of (18), we multiply by similar proper scalar fractions the transfer function by components, considering the multiplicities by components, then the orders of the detector will decrease allowing us better detections for noisy systems.

3. EXAMPLES

3.1 *Example 1*

Let us consider the system

$$\dot{e}(t) = \begin{pmatrix} 0 & \cdots & 0 & -d_0 \\ 1 & & \vdots & \vdots \\ & \ddots & & \\ 0 & \cdots & 1 & -d_{n-1} \end{pmatrix} e(t) + \begin{pmatrix} L_1 \\ \vdots \\ L_n \end{pmatrix}, (19)$$

$$\eta(t) = (0 \;\; \cdots \;\; 1)e(t), (20)$$

with negative poles $\lambda_1, \lambda_2, \ldots, \lambda_n$. As example, we shall consider the case when all poles are different. The characteristic polynomial of our system is

$$p(s) = s^n + d_{n-1}s^{n-1} + \cdots + d_1 s + d_0,$$

where

$$\begin{aligned} d_{n-1} &= -(\lambda_1 + \cdots + \lambda_n), \\ d_{n-2} &= \lambda_1\lambda_2 + \cdots + \lambda_{n-1}\lambda_n, \\ &\vdots \\ d_0 &= \lambda_1\lambda_2 \cdots \lambda_n. \end{aligned}$$

The eigenvector corresponding to the pole λ_1 is

$$e_1 = \begin{pmatrix} 1 \\ -(\lambda_2 + \cdots + \lambda_n) \\ \lambda_2\lambda_3 + \cdots + \lambda_{n-1}\lambda_n \\ \vdots \\ (-1)^{n-1}\lambda_2 \cdots \lambda_n \end{pmatrix},$$

thus, to the pole λ_n is

$$e_n = \begin{pmatrix} 1 \\ -(\lambda_1 + \cdots + \lambda_{n-1}) \\ \lambda_1\lambda_2 + \cdots + \lambda_{n-2}\lambda_{n-1} \\ \vdots \\ (-1)^{n-1}\lambda_1 \cdots \lambda_{n-1} \end{pmatrix}.$$

Let L be decomposed in the basis $e_1, \ \ldots, \ e_n$, this is:

$$L = \sum_{i=1}^{n} l_i e_i = \sum_{j=1}^{M} l_{i_j} e_{i_j}.$$

The linear combination with non zero coefficients, $l_{i_j} \neq 0, \ j = 1, \ldots, M$. Then, the reachability subspace of (19), generated by the basis elements $e_{i_1}, \ldots, e_{i_M}$.

Let us suppose that for an L, the reachability subspace is generated by the elements $e_1, \ldots, e_{i-1}, e_{i+1}, \ldots, e_n$. Then λ_i will be a root of the polynomial

$$L_n s^{n-1} + L_{n-1}s^{n-2} + \cdots + L_1 = p_L(s),$$

that is,

$$\sum_{j=1}^{n} L_j \lambda_i^{j-1} = 0.$$

Hence, if $p_l(-s)$ is Hurwitz polynomial, that is, all roots of $p_L(s)$ has positive real parts, then the reachability subspace of (19) must be the whole space (let us remember that λ_i's are negative poles).

3.2 *Example 2*

Let us consider the system of error

$$\dot{e}(t) = \begin{pmatrix} 0 & 0 & d_1 & e_1 \\ 1 & 0 & d_2 & e_2 \\ 0 & 1 & d_3 & e_3 \\ 0 & 0 & d_4 & e_4 \end{pmatrix} e(t) + \begin{pmatrix} a \\ b \\ 1 \\ 1 \end{pmatrix} v_1 +$$

$$+ \begin{pmatrix} a \\ b \\ 1 \\ -1 \end{pmatrix} v_2, \quad (21)$$

$$\eta(t) = \begin{pmatrix} 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix} e(t), \quad (22)$$

where the polynomial $\lambda^2 + b\lambda + a$ has roots with positive real parts that is $\lambda^2 - b\lambda + a$ is a Hurwitz polynomial. Then, supposing that output separability holds for (21), (22), the relations

$$\begin{aligned} d_1 + e_1 &= a(d_4 + e_4), \\ a + (d_2 + e_2) &= b(d_4 + e_4), \\ b + (d_3 + e_3) &= (d_4 + e_4), \\ d_1 - e_1 &= -a(d_4 - e_4), \\ a + (d_2 - e_2) &= -b(d_4 - e_4), \\ b + (d_3 - e_3) &= -(d_4 - e_4) \end{aligned}$$

can be deduced. Now, we can choose as independent parameters d_1 and d_4. So, the structure matrix of (21) will has the form

$$(A - DC) = \begin{pmatrix} 0 & 0 & d_1 & ad_4 \\ 1 & 0 & b\frac{d_1}{a} - a & bd_4 \\ 0 & 1 & \frac{d_1}{a} - b & d_4 \\ 0 & 0 & d_4 & \frac{d_1}{a} \end{pmatrix}.$$

Its characteristic polynomial is

$$\left[\left(\lambda - \frac{d_1}{a}\right)^2 - d_4^2\right](\lambda^2 + b\lambda + a) = p(\lambda),$$

with roots of positive real parts independently of the gain parameters d_1, d_4. Hence simultaneously output separability and stability can not be hold.

However, Theorem 1 can be applied and our method solves the change detection and isolation problem. Indeed, system (21), (22) is observable, and the fault signatures satisfied the required weak failure observability and weak failure separability.

4. CONCLUSION

The weak failure observability and weak failure separability of a detectable diagnostic system are necessary conditions. In this paper it was proven that they are also sufficient to decoupling the failure signals by a Luenberger observer and dynamic post-filter into decoupled detectors. The use of detectors may fail only for noisy systems with noise of high level and small failure signal, in consequence of the multiple integration. The method ignores completely the well-known $C - A$ invariance. Thus, the computation is easy because design requirement is an asymptotically stable Luenberger's observer with left invertible transfer function of error equation.

5. REFERENCES

Edelmayer, A., J. Bokor and F. Szigeti (1997*a*). A geometric view of observers based methods for detection and isolation of faults in time varying and bilinear systems. In: *Proc. SAFEPROCESS of IFAC*. Hull - England. pp. 140–146.

Edelmayer, A., J. Bokor, F. Szigeti and L. Keviczky (1997*b*). Robust detection filter design in the presence of time varying systems perturbations. *Automatica* pp. 471–480.

Hou, M. and R.J. Patton (Submitted). Input observability and input reconstructibility. *Automatica*.

Keviczky, L., J. Bokor, A. Edelmayer and F. Szigeti (1992). Detection filter design in the presence of time varying system perturbations. In: *Proc. 31th CDC*. Tucson - USA. pp. 3091–3093.

Massoumnia, M.A. (1986). A geometric approach to the synthesis of failure detection filters. *IEEE Trans. Aut. Control* pp. 839–846.

Patton, R.J. and M. Hou (1997). Fault observability and fault reconstruction for dynamical systems. In: *Proc. of Workshop On-line Fault Detection and Supervision in the Chemical Process Industry*. p. Session 1B.

Szigeti, F. (1992). A differential algebraic condition for controlllability of time varying linear systems. In: *Proc. 31th CDC*. Tucson - USA. pp. 3088–3090.

Szigeti, F. and R. Tarantino (1998). Augmented space method for fault detection and isolation filter. In: *Proc. of Workshop On-line Fault Detection and Supervision in the Chemical Process Industry*. p. Session 2.

Szigeti, F., C.E. Vera-Rojas and A. Ríos-Bolívar (1997*a*). Stabilization and detection of time varying linear systems. In: *Proc. 4th ECC*. Brussels - Belgium. pp. TH–M D4.

Szigeti, F., J. Bokor, A. Edelmayer and R. Tarantino (1997*b*). Fault detection filter design for linear time varying systems: Algebraic-geometric approach. In: *Proc. 4th ECC*. Brussels - Belgium. pp. TH–M H6.

Szigeti, F., J. Bokor and A. Edelmayer (1995). On the reachability subspaces of time varying linear systems. In: *Proc. 3rd ECC*. Rome - Italy. pp. 2980–2985.