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Diagnosis Based-Faultand Isolation of Faults in MZSHSYSTEM Sensors by DECOUPLED OBSERVER

Zazi Malika, Hajji Youssef, Marouane Rayyam, Chtouki Ihssane

Professor, Department of Electrical Engineering,MOHAMMED V UNIVERSITY IN RABAT, Morocco

PhD Student, Department of Electrical Engineering,MOHAMMED V UNIVERSITY IN RABAT, Morocco

PhD Student, Department of Electrical Engineering,MOHAMMED V UNIVERSITY IN RABAT, Morocco

PhD Student, Department of Electrical Engineering,MOHAMMED V UNIVERSITY IN RABAT, Morocco

ABSTRACT: In this article we present an observer based method of using the residuals so that in case of additive failure at the sensors of this system, the failure can be represented as unknown input with a known direction, called failure direction. Residuals are evaluated using ker of some matrix the residual will show it by a level variation, and then according to mathematical calculations this technique is introduced to locate the fault. Resulted fault detection system is tested with a multi zone space heating system MZSH in MATLAB environment. Result show that the fault detection and isolation system of sensors is robust and has a good performance.

KEYWORDS: Observers, luenberger observer, analytical redundancy, residual, sensitivity, decoupling.

I. INTRODUCTION

The problem of fault diagnosis consists of detecting and isolating fault present in a system. As technical systems become more and more complex and the demands for safety, reliability and environmental friendliness are rising, fault diagnosis is becoming increasingly important.

Extensive reviews of different fault detection and isolation methods can be found in the literature. Existing methods can be grouped into three general categories: quantitative model-based methods, qualitative model-based methods and data driven methods. Our interest is on the class of quantitative model-based techniques, namely observer-based approach, parameter estimation approach and parity-space approach, which have received considerable attention in recent years [1], [2]. These approaches use the mathematical model of the process to estimate its normal behaviour. Differences between the estimated and the actual behaviour are symptoms or fault indicators. These differences are called residuals. Later, the residuals are evaluated aiming at to localize the fault.

II. FAULT-DETECTION WITH OBSERVER

One approach to fault diagnosis, providing potentially good performance and in which the need for additional hardware is minimal, is model-based fault diagnosis with residuals. A residual is a signal that is zero when the system under diagnosis is fault-free and non-zero when particular faults are present in the system. Residuals are typically generated by using a mathematical model of the system and measurements from sensors and actuators. This process is referred to as residual generation. In this paper we consider an observer based residual generation for linear systems.

A. LUENBERGER OBSERVER:

We consider that the system to supervise is a determinist system that has for model the next linear model:

$$\begin{aligned} \dot{x} &= Ax + Bu \\ y &= Cx + Du \end{aligned} \quad (1)$$

The state $\hat{z}$ is an estimation of a linear function:

$$z = Vx \quad (2)$$

$$\dot{\hat{z}} = \Pi\hat{z} - Ty + Ru \quad (3)$$

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The dynamic system (3) is an observer of system (1) if and only if: Π is Hurwitz and:

$$VA + TC = \Pi V \quad (4)$$
$$VB + TD = R \quad (5)$$

Equation (4) is named fundamental equation of the observer
Proof: derivative of the observer error is

$$\varepsilon = z - \hat{z}$$
$$\Rightarrow \dot{\varepsilon} = \dot{z} - \dot{\hat{z}} = V\dot{x} - \Pi\hat{z} + Ty - Ru + \Pi z - \Pi z$$
$$\dot{\varepsilon} = V(Ax + Bu) + \Pi(z - \hat{z}) + T(Cx + Du) - Ru - \Pi Vx$$
$$\dot{\varepsilon} = \Pi\tilde{z} + (VA + TC - \Pi V)x + (VB - TD - R)u$$

$\dot{\varepsilon} = \Pi\tilde{z}$ If and only if

$$VA + TC - \Pi V = 0 \text{and} VB - TD - R = 0 \quad (6)$$

The dynamic system output $\hat{\eta}$:

$$(O) \quad \begin{array}{l} \hat{z} = \Pi\hat{z} - \dot{T}y + Ru \\ \hat{\eta} = Q_z\hat{z} + Q_y y + Q_u u \end{array} \quad (7)$$

Is an estimate of $\eta = L_x x + L_u u$ if and only if Π is stable and if exist V, as:

$$VB + TD = R \quad (8)$$
$$VA + TC = \Pi V \quad (9)$$
$$Q_z V + Q_y C = L_x \quad (10)$$
$$Q_y D + Q_u = L_u \quad (11)$$

(10) and (11) are named Projection equation
If $\hat{\eta}$ is an estimation ofη, then $\hat{z}$ is an estimation of linear function of x, z (t) =Vx.
Proof: errors estimation $\varepsilon = z - \hat{z}$
and$e = \eta - \hat{\eta}\dot{\varepsilon} = \Pi\varepsilon$
Because:

$$VA + TC = \Pi V \text{and} VB + TD = R \quad (12)$$
$$\text{And } e(t) = \eta(t) - \hat{\eta}(t) \quad (13)$$
$$= L_x + L_u - Q_z\hat{z} - Q_y y - Q_u u + Q_z z - Q_z z$$

$y = Cx + Du$ (13)

$$e(t) = Q_z(z - \hat{z}) + (L_x - Q_z V - Q_y C)x + (L_u - Q_u - Q_y D)u (14)$$

Whence

$$e(t) = Q_z\varepsilon + (L_x - Q_z V - Q_y C)x + (L_u - Q_u - Q_y D)u \quad (15)$$

$\lim_{t\to\infty} e(t) = 0$if and only if:
$Q_z V + Q_y C = L_x \text{and} Q_y D + Q_u = L_u$

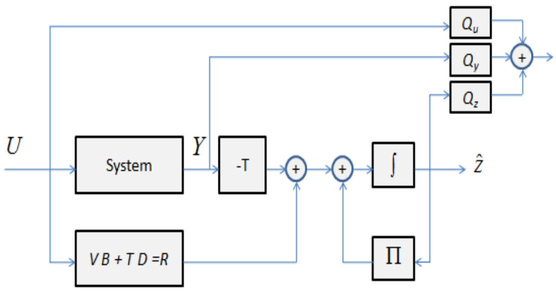

Fig.1: Luenberger observer

In the following we will present the notion of elementary observers and their role in detection and localization of faults

B. ELEMENTARY OBSERVER:

Definition:
An elementary observer is an observer of one dimension that estimates a linear combination of the state vector
z = vxAn elementary observer with β dynamic is written

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$$:\dot{\hat{z}} = \beta\hat{z} - ty + ru \text{ with } \beta < 0 \quad (16)$$

and :

$$vB + tD = r \quad (17) \quad \text{and} \quad vA + tC = \beta v \qquad (18)$$

All elementary observers with β dynamic ($V(\beta)$et $T(\beta)$) satisfy the fundamental equation :

$$V(\beta)A + T(\beta)C = \beta V \qquad (19)$$

$$V(\beta)[A - \beta I] + T(\beta)C = 0 \qquad (20)$$

So we find all elementary β dynamic observers by searching a matrix $[V(\beta)\ T(\beta)]$ of maximal rank verifying:

$$[V(\beta)\ T(\beta)]\begin{bmatrix} A - \beta I \\ C \end{bmatrix} = 0 \qquad (21)$$

Any vector v belonging to the space generated by the lines of V (β) corresponds to elementary β dynamic observers.

Residuals generation: [7] [9]

In this section, we seek to construct a residuals generation, for this we construct an elementary observer which output ή is an estimation of residual.

$$\begin{aligned} \dot{\hat{Z}} &= \Pi\hat{Z} - Ty + Ru \\ \hat{\eta} &= Q_z\hat{z} + Q_y y + Q_u u \end{aligned} \qquad (22)$$

Is to $res = L_x x + L_u u$ so to generate a residual we should take: $L_x = 0$ and $L_u = 0$ because r (t) = 0 if there is no fault in the process.

So the projection equations are written:

$$Q_z V + Q_y C = 0 \qquad (23)$$

$$Q_y D + Q_u = 0 \qquad (24)$$

We must require that $[Q_z Q_y Q_u]$ different of zero In this case the problem is to choose V satisfying the fundamental equation of the observer and that ensures the existence of a non-zero solution to the equation:

$$[Q_z Q_y]\begin{bmatrix} V \\ C \end{bmatrix} = 0 \qquad (25)$$

This may be achieved by increasing the size of the vector estimated by the state of the observer, i.e. Increase the size of V by adding elementary observers to have a relationship of dependency between $\hat{z}, y$ et u. this will happen with the more (n – rank(C)).

The procedure for constructing a residual generator is the following:

Choose dynamics β_j in number q sufficient to have a vector $[\theta_c\theta_1\theta_2 \ldots \theta_q]$ not null, solution of the following equation :

$$[\theta_c\theta_1\theta_2 \ldots \theta_q]\begin{bmatrix} C \\ V(\beta_1) \\ \cdot \\ \cdot \\ V(\beta_j) \end{bmatrix} = 0 \qquad (26)$$

Where$[V(\beta_j)\ T(\beta_j)]$, j=1 …q, are matrixes with maximal rank verifying:

$$[V(\beta_j)\ T(\beta_j)]\begin{bmatrix} A - \beta_j I \\ C \end{bmatrix} = 0 \qquad (27)$$

Build an observer of dimension q by concatenating elementary q observers:

$$\Pi = \begin{bmatrix} \beta_1 & \cdot\cdot & \cdot\cdot \\ \cdot\cdot & \ddots & \cdot\cdot \\ \cdot\cdot & \cdot\cdot & \beta_{n-1} \end{bmatrix}, V = \begin{bmatrix} v_1 \\ \cdot\cdot \\ v_{n-1} \end{bmatrix}, T = \begin{bmatrix} t_1 \\ \cdot\cdot \\ t_{n-1} \end{bmatrix} \qquad (28)$$

$$VB + TD = R$$

$$Q_y = e_c, Q_z = [1 \ldots 1] \text{ et } Q_u = -e_c D$$

A scalar residual is generated by:

$$res = Q_y y + Q_z\hat{z} + Q_u u \qquad (29)$$

Residuals generation:

The problem is to find the triplet (e_c, t_i, v_i) satisfying the equation of the observer and the residuals generator:

$$e_c C + Q_z V = 0$$

Of $VA + TC = 0$ it follows that:

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$$v_i(A-\beta_i)+t_iC=0 \Leftrightarrow v_i=-t_iC(A-\beta_i)^{-1}\ (i=1\ldots.q) \qquad (30)$$

Then

$$e_cC - t_1C(A-\beta_1)^{-1} - \cdots - t_qC\left(A-\beta_q\right)^{-1}=0 \qquad (31)$$

We pose $C_i = C(A-\beta_i)^{-1}$

$$\text{then } e_cC - t_1C_1 - \cdots - t_qC_q = 0 \qquad (32)$$

This equation can be written in matrix form:

$$\begin{bmatrix} C^T & C_1^T & \cdots & C_q^T \end{bmatrix}\begin{bmatrix} e_c^T \\ t_1^T \\ \vdots \\ t_q^T \end{bmatrix}=0 \Rightarrow \begin{bmatrix} e_c^T \\ t_1^T \\ \vdots \\ t_q^T \end{bmatrix} \in \ker\begin{bmatrix} C^T & C_1^T & \cdots & C_q^T \end{bmatrix} \quad (33)$$

(Ker denotes the kernel)

We can get all the solution of $\begin{pmatrix} {e_c}^T \\ {t_i}^T \end{pmatrix}$ by searching the kernel of the matrix:

$$S=[C^T {C_1}^T \ldots\ldots\ldots {C_q}^T] \qquad (34)$$

Then residuals generator equation is:

$$\dot{\hat{z}} = \Pi\hat{z} - Ty + (VB+TD)u \qquad (35)$$

$$res = \sum_{i=1}^{i=q} z_i + e_cy - e_cDu \qquad (36)$$

We can summarize this procedure on the following algorithm:

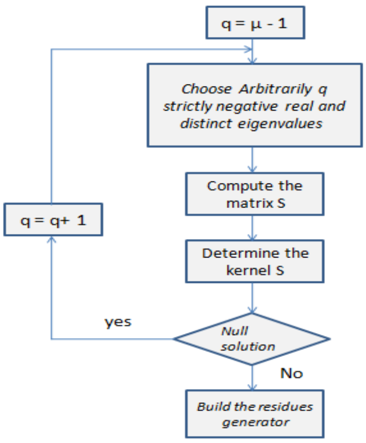

Fig.2: residuals generation procedure

Simulation of residual in fault-free case and in the presence of fault sensor:

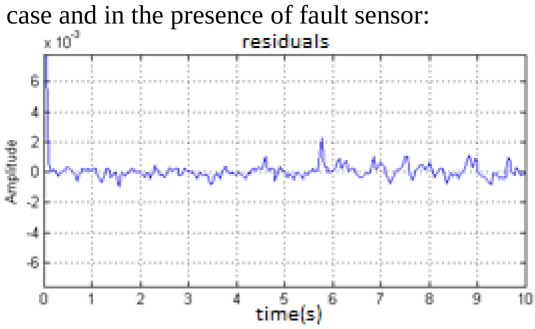

Fig.3: The fault-free case residual

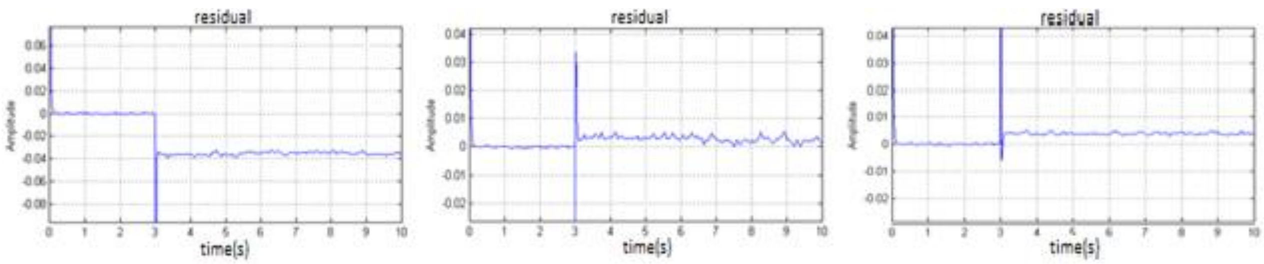

Fig.4: residual in the presence sensor fault, from the left to the right, 1, 2, 3

Note that there in case there are no faults , the residual remains zero, and it changes value in the presence of a fault on one of the sensors but since the signatures obtained are identical the fault cannot be localized

C. DECOUPLING AND SENSITIZATION:

Failure and residuals:
a failure d will be represented as an unknown input, but acts in a known direction (E, F), called direction of failure and corresponds to the following state model:

$$\dot{x}(t) = Ax(t) + Bu(t) + Ed$$
$$y(t) = Cx(t) + Du(t) + Fd \quad (37)$$

Thus, a failure of ith sensor is treated as an additive disturbance at the ith measured variable, so for the model, we take:

$$E = 0 \text{ et } F = \begin{pmatrix} 0 \\ 0 \\ 1 \\ \dots \end{pmatrix} \rightarrow i^{th} \text{line} \quad (38)$$

Residuals are used to detect and locate faults if possible. For fault isolation, you must create structured residuals that are sensitive to some failures and decoupled from the other failures.
Decoupling: a residual is decoupled from a failure d if it is insensitive to this failure.
Here we consider two types of decoupling:
The dynamic or pulse decoupling where the residual is zero whatever the failure d (t)
The static decoupling: in this case, requires that the residual is zero in steady-state for step failure.
Calculate the transfer function of the residual towards failure of E, F direction. We have:

$$res = Q_y y + Q_z \hat{z} + Q_u u$$
$$\dot{x}(t) = Ax(t) + Bu(t) + Ed (39)$$
$$y(t) = Cx(t) + Du(t) + Fd$$

Then:

$$res = (Q_y C + Q_z V)x + (Q_y D + Q_u)u - Q_z \varepsilon + Q_y Fd (40)$$

Because:

$$\left.\begin{matrix} Q_z V + Q_y C = 0 \\ Q_y D + Q_u = 0 \end{matrix}\right] : \text{projection equation} \quad (41)$$

Then:

$$res = -Q_z \varepsilon + Q_y Fd \quad (42)$$

We have:

$$\varepsilon = z - \hat{z}$$
$$\dot{\varepsilon} = \dot{z} - \dot{\hat{z}} = V(Ax + Bu + Fd) - \Pi\hat{z} + T(Cx(t) + Du(t) + Fd) - Ru + \Pi z - \Pi z \quad (43)$$
$$= \Pi\varepsilon + (VA + TC - \Pi V)x + (VB + TD - R)u + (VE + TF)d \quad (44)$$

Because:

$$\left.\begin{matrix} VA + TC = \Pi V \\ VB + TD = R \end{matrix}\right] : \text{observer equation} \quad (45)$$

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So the estimation error verifies:
$\dot{\varepsilon} = \Pi\varepsilon + (VE + TF)d$ (p)

Apply the Laplace transform to the equation:

$$p\varepsilon(p) = \Pi\varepsilon(p) + (VE + TF)d(p)$$

$$\varepsilon(p) = (pI - \Pi)^{-1}.(VE + TF).d(p) \qquad (46)$$

$$res(p) = -Q_z\varepsilon(p) + Q_y F\, d(p)$$

$$= \left[Q_y F - Q_z(pI - \Pi)^{-1}(VE + TF)\right]d(p) (47)$$

Dynamic decoupling:
From the equations (45), (46) and (47) residual is found that is dynamically decoupled from the fault d if and only if:

$$Q_y\, F = 0 \quad (48)$$

$$VE + TF = 0 \quad (49)$$

Or $\dot{\varepsilon} = \Pi\varepsilon + (VE + TF)d$, therefore the estimation error is dynamically decoupled from the failure if and only if:

$$VE + TF = 0$$

Therefore the residual can be seen dynamically decoupled from failure d if and only if the observer also and if $Q_y\, F = 0$.
Conditions (49) called constraint decoupling then add to the fundamental equation during the synthesis of the observer.
Construction of dynamically decoupled residuals:
Choose dynamic β_j in number q sufficient that a vector $[\varepsilon_0 \quad \varepsilon_1 \quad \varepsilon_2 \quad \cdots \quad \varepsilon_q]$ is the nonzero solution of the following equation:

$$[\varepsilon_0 \quad \varepsilon_1 \quad \varepsilon_2 \quad \cdots \quad \varepsilon_q]\begin{bmatrix} C & F \\ V(\beta_1) & 0 \\ \vdots & \vdots \\ V(\beta_j) & 0 \end{bmatrix} = 0, \qquad (50)$$

Where $[V(\beta_1) \quad T(\beta_1)]$, $j = 1, \ldots\ldots q$, are matrices of maximal rank satisfying:

$$[V(\beta_1) \quad T(\beta_1)]\begin{bmatrix} A - \beta_j I & E \\ C & F \end{bmatrix} = 0, \qquad (51)$$

Build the observer and the residual as in points 2) and 3) of the procedure (1).
Determination of residuals generator dynamically decoupled
Arbitrarily choose q strictly negative real eigenvalues.
We pose:

$$\Pi = \begin{bmatrix} \beta_1 & \cdots & 0 \\ \vdots & \ddots & \vdots \\ 0 & \cdots & \beta_q \end{bmatrix} T = \begin{bmatrix} t_1 \\ \vdots \\ t_q \end{bmatrix} V = \begin{bmatrix} v_1 \\ \vdots \\ v_q \end{bmatrix}$$

$$Q_y = \varepsilon_c\, , Q_z = [1 \quad \cdots \quad 1] \text{ et } Q_u = -\varepsilon_c\, D$$

The problem is to find the triplet (checking the equations of the observer and generator residuals dynamically decoupled from a failure (E, F).

$$\varepsilon_c C + Q_z V = 0 \leftrightarrow \varepsilon_c + v_1 + v_2 + \cdots v_q = 0$$

$$VA + TC = \Pi V \leftrightarrow v_i(A - \beta_i I) + t_i C = 0 \leftrightarrow v_i$$

$$V\,E + T\,F = 0 \leftrightarrow v_i E + t_i\, F = 0\, ,$$

$i = 1 \ldots.q$ (Decoupling equation)

$$v_i = -t_i C(A - \beta_i)^{-1}, v_i E + t_i F = 0 \leftrightarrow t_i$$

we pose :

$$C_i = -C(A - \beta_i I)^{-1}$$

$$F_{di} = (F - C(A - \beta_i I)^{-1}E) = F + C_i E$$

Couples(ε_c, t_i) satisfy the equations

$$\varepsilon_c + t_1 C_1 + \cdots + t_q C_q = 0$$

$$\varepsilon_c F = 0$$

$$t_1 F_{d1} = 0$$

$$\vdots$$

$$t_q F_{dq} = 0$$

All solutions $\begin{bmatrix} \varepsilon_c^T \\ t_i^T \end{bmatrix}$ belongs to the kernel of matrix S1

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$$S_1 = \begin{bmatrix} C^T & C_1^T & \cdots & \cdots & C_q^T \\ F^T & 0 & 0 & \cdots & 0 \\ 0 & F_{d1}^T & 0 & \cdots & 0 \\ 0 & 0 & F_{d2}^T & \cdots & 0 \\ \vdots & \cdots & \cdots & \ddots & \vdots \\ 0 & \cdots & \cdots & 0 & F_{dq}^T \end{bmatrix}$$

We can summarize this procedure on the following algorithm:

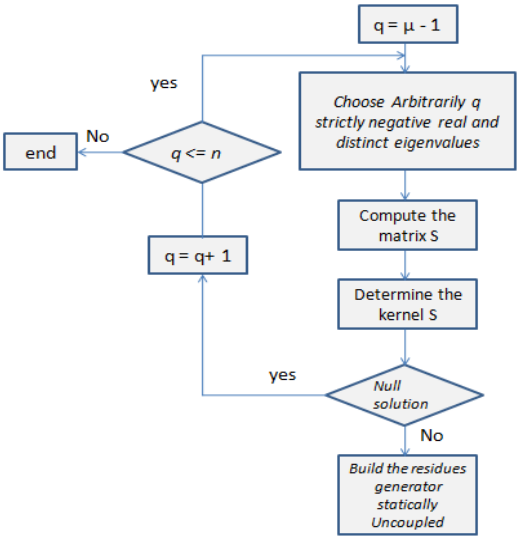

Fig.5: residuals generation procedure

Static decoupling:

$$res(p) = [Q_y.F - Q_z.(pI - \Pi)^{-1}(VE + TF)]d(p)$$

$$stat = \lim_{t \to +\infty} res(t) = \lim_{p \to 0} p\, res(p)$$

$$stat = [Q_y.F - Q_z.(\Pi)^{-1}(VE + TF)]d \qquad (52)$$

Now if d varies over time, stat is a good approximation of the residual if the dynamicschosen for the observer is fast enough to that of the fault.

The condition of static decoupling is thus written as: $[Q_y.F + Q_z.(\Pi)^{-1}(VE + TF)] = 0$ (53)

Residuals generation statically decoupled is given by the following procedure:

Arbitrarily choose q strictly negative real eigenvalues.

We have:

$$\varepsilon_c C + t_1 C_1 + t_2 C_2 + \cdots + t_q C_q = 0$$

$$C_i = -C(A - \beta_i I)^{-1}$$

$$\varepsilon_c F + w_1 + w_2 + \cdots + w_q = 0 \; w_i = \frac{1}{\beta_i}(v_i E + t_i F)$$

$$v_i = t_i C_i \rightarrow w_i = \frac{1}{\beta_i} t_i (F + C_i E),$$

$$\text{we set } F_d = \frac{1}{\beta_i}(F + C_i E) \qquad (54)$$

The system of equations becomes:

$$\varepsilon_c C + t_1 C_1 + t_2 C_2 + \cdots + t_q C_q = 0$$

$$\varepsilon_c F + t_1 F_{s1} + t_2 F_{s2} + \cdots + t_q F_{sq} = 0 \qquad (55)$$

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All the solution $\begin{bmatrix} \varepsilon_c^T \\ t_i^T \end{bmatrix}$ belongs to the kernel of matrix:

$$S2 = \begin{bmatrix} C^T & C_1^T & \cdots & C_q^T \\ F^T & F_{s1}^T & \cdots & F_{sq}^T \end{bmatrix} \quad (56)$$

If the solution is null add an elementary observer (q = q +1)
Note that the matrix S1 is greater than the S and S2 matrix, so its kernel will be smaller. In fact we have more statically decoupled residuals than dynamically.
The procedure can be summarized by the same algorithm as fig.7
The work presented is part of the diagnosis sensor with a single additive default.
In the next section, we will present the application of elementary observers for the diagnosis of faults sensor MZSH system.

III. DIAGNOSIS OF MZSH SENSORS

The simulated system is the HVAC [3], [4] known as the MZSH represented (Multizone Space Heating Systems).

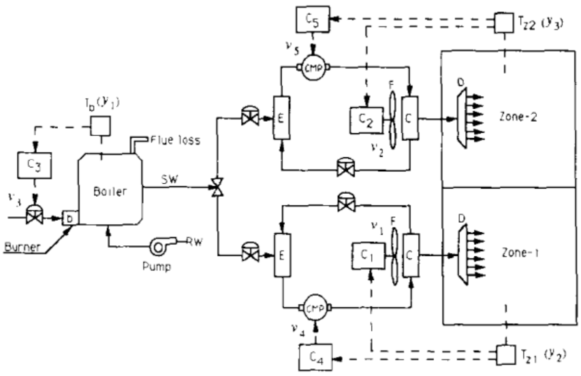

Fig.6: The MZSH system

CMP: compressor; E: evaporator; C: condenser; D: diffuser; Ci: controller (i=1, 2,.., 5) ; SW : supply water
RW: return water; F: fan
The MZSH is composed of a boiler that is used to provide water to a moderate temperature between (16 -32) to an intersection of heat by evaporation of the pump of heat, every zone is installed with its own pump of heat, that works in cycle of compression-cooling.
The pump receives the hot energy of the source of water is increased this energy to a temperature to raise and it puts it back to the condenser, a fan and of the conducts is used to extract the heat of the condenser and to make pass it toward the zones through distributors.
The problem of control that one is not going to treat here but one leaves it for one future works research, consist in controlling the temperature of the two zones so the one of the furnace with the minimum of energy.
One can decompose the system in three stations:
Station 1: the Boiler; Station 2: zone1; Station 3: zone2
The output of every station must be made to follow desire some points that is known a priori. The task of regulation uses for: The station 1: input v3 to control the output y1 with thecontroller c3
The station 2: inputs v1; v4 to control the output y2 with thecontrollers c1; c4
The station 2: inputs v2; v5 to control the output y3 with the controllers c2; c5
V3: the mass debit (air); V1, V2: the speed of the fan; V4, V5: the energy in the input of the compressor
Y1, Y2, and Y3: Are respectively the temperature of the boiler, zone1 and zone2.
With the parameters of the system given in the annex 1 and the point of realistic working defined in the annex 2, the model decentralized linear for the MZSH system is:

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$$\Delta\dot{x}(t) = A.\Delta x(t) + B1\Delta v3 + B2\begin{pmatrix}\Delta v1\\ \Delta v4\end{pmatrix} + B3\begin{pmatrix}\Delta v2\\ \Delta v5\end{pmatrix} + E1\Delta d1(t) + E2\Delta d2(t)$$

$\Delta y1(t) = C1\Delta x(t)$
$\Delta y2(t) = C2\Delta x(t)$

$$\Delta y3(t) = C3\Delta x(t)$$

With $\Delta x = [\Delta Tb \quad \Delta Tl1 \quad \Delta Th1 \quad \Delta Tz1 \quad \Delta Tl2 \quad \Delta Th2 \quad \Delta Tz2]$
$\Delta u = [\Delta v3 \quad \Delta v1 \quad \Delta v4 \quad \Delta v2 \quad \Delta v5]^T$
$\Delta d = [\Delta Te \quad \Delta Tp]^T$

Either the matrixes A, Bi, Here, i=1, 2, 3, and Ej, j=1, 2 have the values below:

$$A = \begin{bmatrix} -19.525 & 7.988 & 0.0 & 0.0 & 7.988 & 0.0 & 0.0 \\ 28.361 & -29.759 & 1.134 & 0.0 & 0.0 & 0.0 & 0.0 \\ 0.0 & 1.134 & -9.529 & -8.130 & 0.0 & 0.0 & 0.0 \\ 0.0 & 0.0 & 3.635 & -5.054 & 0.0 & 0.0 & 0.2364 \\ 28.361 & 0.0 & 0.0 & 0.0 & -29.759 & 1.134 & 0.0 \\ 0.0 & 0.0 & 0.0 & 0.0 & 1.134 & -10.546 & 9.147 \\ 0.0 & 0.0 & 0.0 & 0.2659 & 0.0 & 4.090 & -5.685 \end{bmatrix}$$

$$B1 = \begin{bmatrix} 80.698 \\ 0.0 \\ 0.0 \\ 0.0 \\ 0.0 \\ 0.0 \\ 0.0 \end{bmatrix}; B2 = \begin{bmatrix} 0.0 & 0.0 \\ 0.0 & 92.442 \\ -160.103 & 133.248 \\ 71.586 & 0.0 \\ 0.0 & 0.0 \\ 0.0 & 0.0 \\ 0.0 & 0.0 \end{bmatrix}; B3 = \begin{bmatrix} 0.0 & 0.0 \\ 0.0 & 0.0 \\ 0.0 & 0.0 \\ 0.0 & 0.0 \\ 0.0 & -96.586 \\ 148.033 & 137.428 \\ 66.189 & 0.0 \end{bmatrix}$$

$$E1 = [1.774 \quad 0.2642 \quad 0.2642 \quad 0.0 \quad 0.2642 \quad 0.2642 \quad 0.0]$$
$$E2 = [0.0 \quad 0.0 \quad 0.0 \quad 1.1818 \quad 0.0 \quad 0.0 \quad 1.3296]$$
$$C1 = [1 \quad 0 \quad 0 \quad 0 \quad 0 \quad 0 \quad 0]; C2 = [0 \quad 0 \quad 0 \quad 1 \quad 0 \quad 0 \quad 0]$$
$$C3 = [0 \quad 0 \quad 0 \quad 0 \quad 0 \quad 0 \quad 1]$$

The residuals generation:

In the diagnosis, there is no universal solution [5]. The choice of generating, evaluation and decision steps depends on the type of fault diagnosed.[8]The parity space, parameter estimation and observers can generate residuals that have special characteristics. Each of these methods provides complementary information for the detection and localization of faults [6]. In our case, the residual generation continuously using elementary observers is presented.

The figure below shows the block diagram used in the generation stage of residuals:

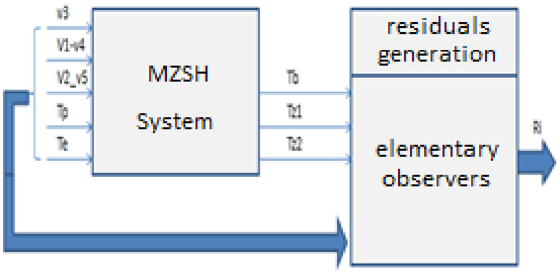

Fig.7: residuals generation

Elaboration of an observer for the detection and localization

The purpose of this section is to build three elementary observers to detect and localize sensor fault using luenberger and elementary observers by following the procedure in Chapter 2

So it comes to synthesized three observers witch each is insensitive to a single fault.

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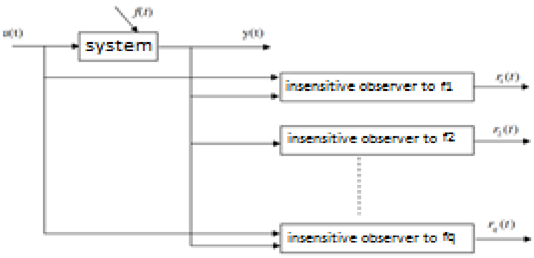

Fig.8: structure of generalized observers

We find the values of the matrix Ri, Ti, Aqi, and QyiQzi. With i = 1, 2, 3.

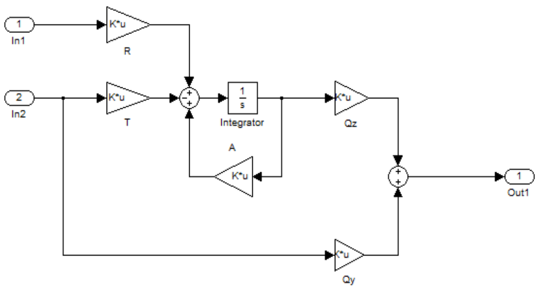

Fig.9: interne structure of observers

The first step to build an elementary observer is to choose the eigenvalues of the observer, their norm must be greater than system's eigenvalues, the table below gives the eigenvalues chooses:

eigenvalues	
System	Observer
-46.5563	-75
-2.784	-60
-1.4564	-50
-7.2798 + 4.9381i	
-7.2798 - 4.9381i	
-14.6751	
-29.8252	

Table.1: eigenvalues system / observer

The matrix Aq is the same for all three observers:

$$Aqi = \begin{bmatrix} -75 & 0 & 0 \\ 0 & -60 & 0 \\ 0 & 0 & -50 \end{bmatrix}$$

Observer 1: decoupled from fault in sensor 1:

$$T1 = \begin{bmatrix} -0.0337 & -1.1359 & -1.4715 \\ -0.0630 & -0.0823 & 0.4300 \\ 0.0139 & 0.5117 & 0.2924 \end{bmatrix}$$

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$$Qy1 = \begin{bmatrix} -3.208e^{-4} & -0.0064 & -0.0066 \end{bmatrix}$$
$$Qz = \begin{bmatrix} 1 & 1 & 1 \end{bmatrix}$$
$$R1 = \begin{bmatrix} -0.0627 & 1.2924 & -0.1339 & 1.6144 & -0.2032 & -0.0019 & 0.0474 \\ 0.2014 & 0.1241 & 0.0480 & -0.6327 & 0.1596 & 0.0042 & -0.0089 \\ -0.1127 & -0.9577 & 0.0860 & -0.5436 & 0.0436 & -0.0018 & -0.0221 \end{bmatrix}$$

Observer 2: decoupled from fault in sensor 2:

$$T2 = \begin{bmatrix} -1.2424 & -0.8199 & -1.1185 \\ -0.3926 & 0.0263 & 0.4333 \\ 0.1837 & 0.3487 & 0.1867 \end{bmatrix}$$
$$Qz = \begin{bmatrix} 1 & 1 & 1 \end{bmatrix}$$
$$Qy2 = \begin{bmatrix} -0.0202 & -0.0035 & -0.0039 \end{bmatrix}$$
$$R2 = \begin{bmatrix} 2.2035 & 0.9198 & 0.3697 & 1.2135 & 0.3335 & 0.0455 & 0.0353 \\ 1.2458 & -0.0497 & 0.3937 & -0.6496 & 0.5017 & 0.0255 & -0.0113 \\ -1.8228 & -0.6182 & -0.7633 & -0.3053 & -0.8352 & -0.0352 & -0.0146 \end{bmatrix}$$

Observer 3: decoupled from fault in sensor 3:

$$T3 = \begin{bmatrix} -0.9858 & -1.3962 & -0.7349 \\ 0.3333 & 0.5435 & -5.8573e^{-4} \\ 0.0099 & 0.2129 & 0.2947 \end{bmatrix}$$
$$Qz \begin{bmatrix} 1 & 1 & 1 \end{bmatrix}$$
$$Qy3 = \begin{bmatrix} -0.0076 & -0.0054 & -0.0039 \end{bmatrix}$$

$$R3 = \begin{bmatrix} 1.7479 & 1.5829 & 0.2134 & 0.7924 & 0.2846 & 0.0360 & 0.0375 \\ -1.0532 & -0.8021 & -0.2327 & 0.0170 & -0.3449 & -0.0212 & -0.0115 \\ 0.0813 & 0.3958 & 0.0193 & -0.5503 & 0.0604 & -0.0013 & -0.0145 \end{bmatrix}$$

The following block diagram shows the basic bench observers used for diagnosis:
Generators of residuals are:

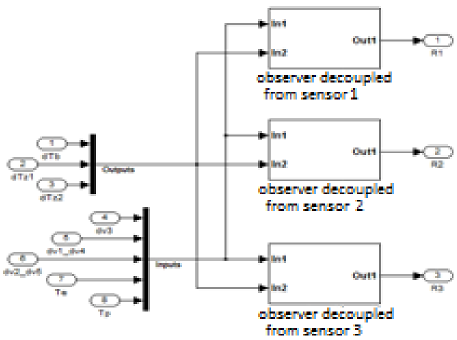

Fig.10 : Elementary observers block diagram

$$res1 = Q_{y1}.y + Q_z.\hat{z}$$
$$res2 = Q_{y2}.y + Q_z.\hat{z}$$
$$res3 = Q_{y3}.y + Q_z.\hat{z}$$

The equations of static decoupling:
$eqds1 = Q_{y1}.F1 + Q_z.inv(Aq).T1.F1 = -1.084E^{-18}$
$eqds2 = Q_{y2}.F2 + Q_z.inv(Aq).T2.F2 = -3.816E^{-17}$

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$$\mathrm{eqds3} = \mathrm{Q_{y3}.F3} + \mathrm{Q_z.inv(Aq).T3.F3} \qquad = 1.507\mathrm{E}^{-17}$$

From the values of the equations of static decoupling we can confirm that each residual is insensitive to a single failure.

IV. SIMULATION

A. CONDITION OF SIMULATION

System: The working of the HVAC has been simulated with the help of Simulink version 1.3c software. The system is provided of three sensors in order to measure the temperature of the boiler, the zone 1 and the zone 2, the measures are affected by a white noise N Gaussian $(0, \sigma = 1e - 7)$

Faults: Faults are modeled by steps which represent the change in nominal values of sensor measurements. The diagnostic system aims to detect and locate faults sensors with the following characteristic:

Additive faults

One fault sensor simultaneously

B. SIMULATION OF RESIDUALS IN THE FAULT-FREE CASE:

The figure shows the behaviour of residuals in the normal operation. The three residuals have an average value very close to zero. This means that modeling errors can be neglected.

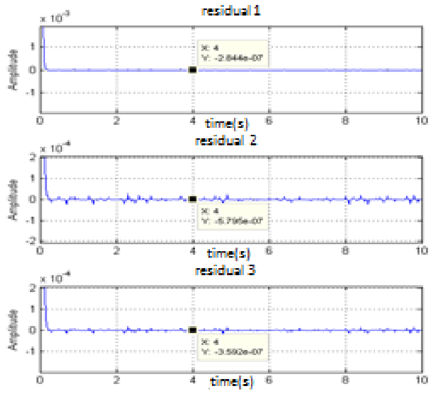

Fig.11: faults-free case residuals

The table below shows the statistical properties of residuals to the normal operation of the system sensors.

	Average	deviation
1st residual	1.3412e-004	1.8585e-007
2nd residual	1.0951e-004	1.5782e-007
3rd residual	1.2554e-004	1.7563e-007

Table.2: statistical properties of residuals in fault-free case

In the following paragraph is studied the sensitivity of the residuals in presence of additive faults on the sensors, and we takes the case of defect on every sensors of the system for the simulation:

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C. SIMULATION OF THE RESIDUALS WHEN SENSOR'S FAULTS ARE PRESENT:

FAULT SENSORS:

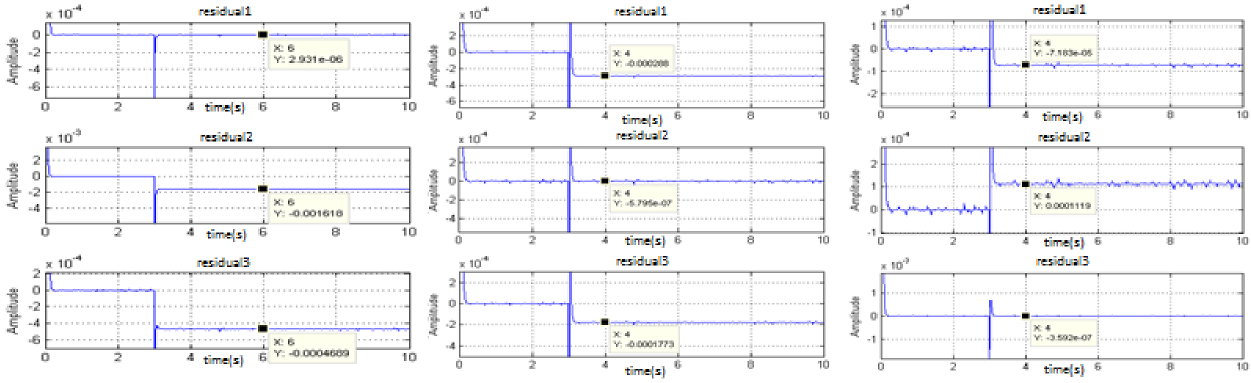

Fig.12 : residuals in the case of fault sensor 1, 2, 3

Result:

The figures above represent the behaviour of the three residuals when a default 5% of the maximum variation is applied to the first sensor at time t = 3s, we note that the first residual is insensitive towards the default, then other residuals changes value, the table below gives the new statistical properties of the residuals :

The table summarizes the results and shows the classification of signatures relative to the sensors faults.

	Average	deviation
1st residual	2.3665e-004	8.1855e-008
2nd residual	-0.0453	0.0042
3rd residual	-0.0218	9.8552e-004

Table.3: statistical properties of the residuals in the case of fault sensor 1

	Fault		
	Sensor1	Sensor2	Sensor3
1st residual	0	A	A
2nd residual	A	0	A
3rd residual	A	A	0

Table.4: Diagnosis matrix for sensor failure

0: no change of the average residual of value
The simulation of MZSH normal operating system and in the presence of default single additive sensors, simulation results show that our diagnostic approach is useful in the detection and localization of sensor faults.

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V. CONCLUSION

This research is an opening on the world of diagnostic, for the generation of structured residuals; we presented the methods that can give residuals statically or dynamically decoupled.
Also the choice of the method of residual generation is an essential step in the diagnosis based on system knowledge, so it is necessary to define a set of specifications to limit the problem. We gave a superficial view on the different stages of residual generation for diagnosis, and then we presented in detail the basic idea of our research work which is the elementary observers and their roles in the detection and fault location sensor.
Diagnosis systems by the method of residuals statically decoupled generations turns out to be a very efficient method however, the use of residuals dynamically decoupled promises better results, future research should focus on the diagnosis of nonlinear systems with simultaneous faults in the sensors and the system itself by introducing the neural networks

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AUTHOR'S BIOGRAPHY

ZaziMalika: received the degree of state engineer in automatics and industrial informatics in 1984, and the Ph.D. degree in electrical engineering in 2006, from The Mohammadia School of engineering in MOHAMMED V UNIVERSITY IN RABAT. Since then she worked as a Research associate at Laboratory of Mechanics, Processes and Industrial Processes with Research Team in Robotics and Control of Linear Systems and Nonlinear. Her research interests includeelectric machines and drives, state variables and parameters estimation, and its application for robust control and diagnosis of multivariable and complex systems, and renewable energy. (E-mail:malika.zazi@um5s.net.ma)

Hajji Youssef: received the MSc degree in Electrical engineering in 2012, from the (Superior Normal School of Technical Education) ENSET in MOHAMMED V UNIVERSITY IN RABAT, Morocco. He is actually working towards a PhD Thesis at Laboratory of Mechanics, Processes and Industrial Processes with Research Team in Robotics and Control of Linear Systems and Nonlinear. His research interests include electric machines and drives, state variables and parameters estimation, and its application for control and diagnosis of multivariable systems (E-mail:youssef.hajji@um5s.net.ma)

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RayyamMarouane: received the MSc degree in Electrical Engineering in 2014, from the (Superior Normal School of Technical Education) ENSET in MOHAMMED V UNIVERSITY IN RABAT. He is actually working towards a PhD Thesis at Laboratory of Mechanics, Processes and Industrial Processes with Research Team in Robotics and Control of Linear Systems and Nonlinear. His research interests include electric machines and drives, state variables and parameters estimation, and its application for diagnostic problems of AC electrical drives. (E-mail: rayyam.marouane@gmail.com).

ChtoukiIhssane: received the MS degree in Electronic and Electrical Engineering Automatics and computer industrial in 2014, from HASSAN II UNIVERSITY in CASABLANCA, MOROCCO, She is actually working towards a PhD Thesis at Laboratory of Mechanics, Processes and Industrial Processes with Research Team in Robotics and Control of Linear Systems and Nonlinear. Her research interests include the integration of photovoltaic systems to the electricity grid; parallel active filtering of harmonics and inverter control-based of neural networks. (E-mail: ihssane.chtouki@gmail.com).