Politehnica University of Bucharest

Department of Automatics and Computer Science

Consideration on real time implementation of leak/fault detection systems in mass transfer networks

Ciprian Lupu, Doinita Chirita, Serban Iftime

TEAM:

- **Doinita Chirita – PhD – UPB, Faculty of Electronics, Telecommunications and Technology Information, assoc. professor** Petroleum-Gas University of Ploieşti
- **Serban Iftime – PhD student, UPB, Faculty of Power Engineering, ELSACO Electronic**
- **Ciprian Lupu – professor, UPB, Faculty of Automatic Control and Computers**
- **... multidisciplinary...**

OUTLINE

… "Sometimes a clearly defined error is the only way to discover the truth" …

Benjamin D. Wiker, The Mystery of the Periodic Table

OUTLINE

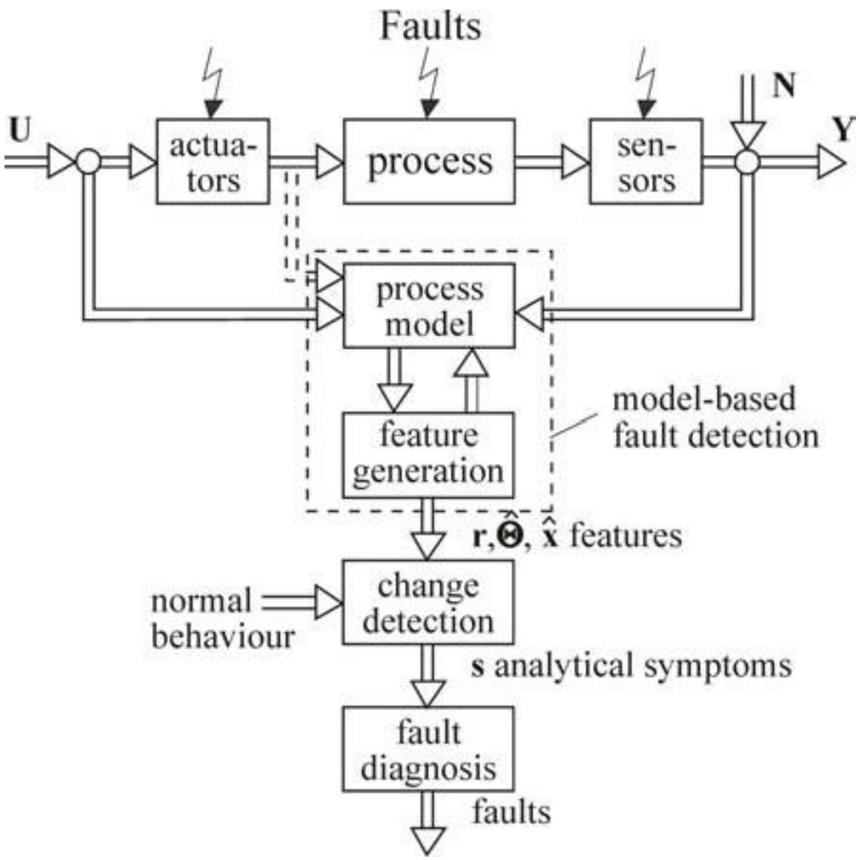
- Introduction
- Proposed idea
- Experimental results
- Conclusions

INTRODUCTION

- Fault or leak detection in the utilities distribution and energy fluids networks represents an objective with significant implications, where, the pollution and safety of life are priorities included.
- The main purpose is to detect the fault situation as fast as possible and to indicate more accurately the affected area/point.

INTRODUCTION

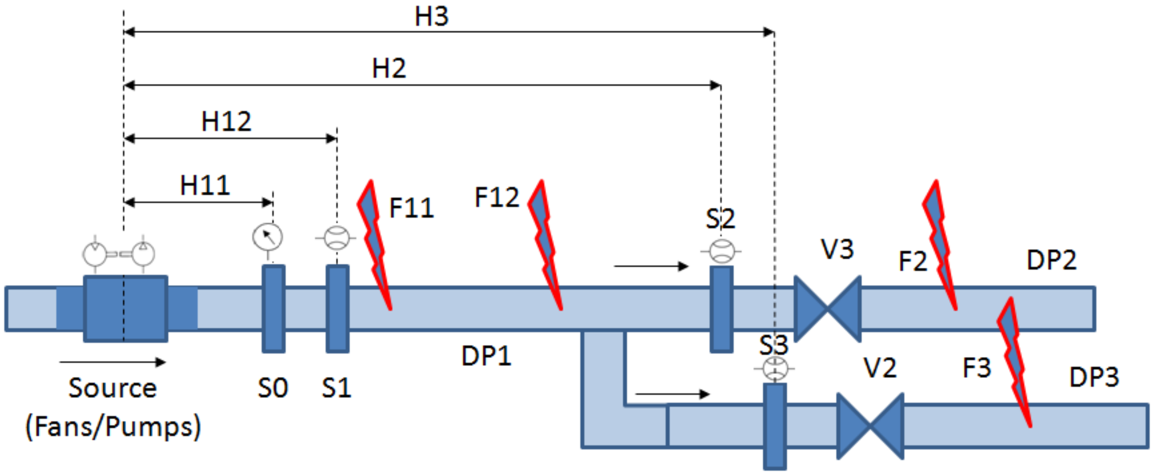
INTRODUCTION



The system proposed by R. Isermann

INTRODUCTION

- Other detection structures (EENVIRO 2016, ICSTCC 2016)

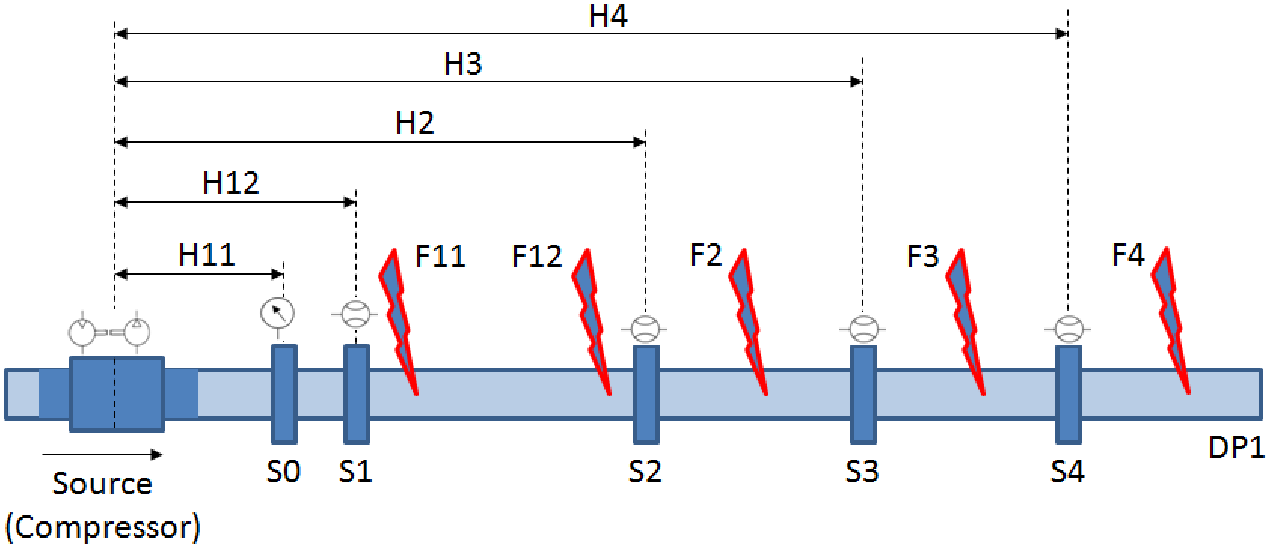


ESU Energy Storage Unit

- OK for (fail) segment detection!!!
- Problems on fail position

PROPOSED IDEA

- The presented solution is based on **real time stimulation** of some transfer functions, **combined with** parameters evolution **supervision**. Computed transfer functions characterize both normal and fault operation system.



PROPOSED IDEA

- The usual steps for the configuration and implementation of the detection system are:

  •data acquisition;

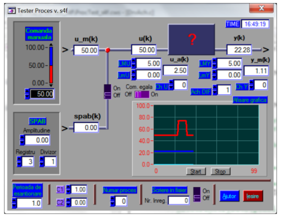
  •identification of the transfer function / models;

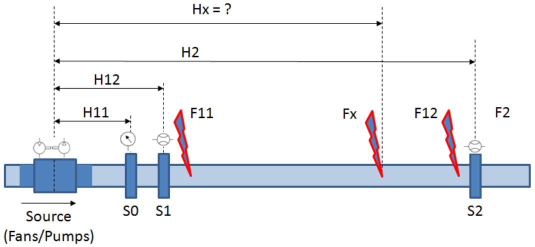
  •the design of the control algorithm;

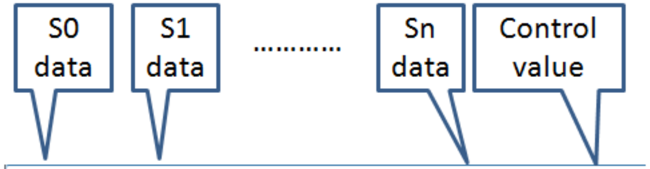
  •the implementation of the detection structure.

PROPOSED IDEA

- **Data acquisition** - the application of some test signals (PRBS - Pseudo Random Binary Sequence) for a normal functioning, in an admissible domain (field), and in a fault condition (with the same sampling period).







42.142685	77.076950	1.039262	9.118152	75.889427	95.000000
42.227524	77.925179	1.124079	9.202975	77.076950	95.000000
42.142685	78.349304	1.208897	9.287798	77.925179	95.000000
42.397190	78.858238	1.208897	9.372621	78.349304	95.000000
41.888184	79.112709	1.293715	9.457444	78.603767	55.000000

PROPOSED IDEA

- **Model identified** - structure can be ARX type. The identification is made with the help of (some) recursive least squares method (RLSM) .

$$y(k)=\frac{q^{-d}B(q^{-1})}{A(q^{-1})}u(k)$$

$$A(q^{-1})=1+a_1q^{-1}+\ldots+a_{nA}q^{-nA}$$

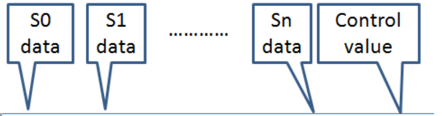
$$R(q^{-1})=b_0+b_1q^{-1}+\ldots+b_{nB}q^{-nB}$$

$$\hat{\theta}(k+1)=\hat{\theta}(k)+F(k+1)\phi(k)\varepsilon^0(k+1),\forall k\in N$$

$$F(k+1)=F(k)-\frac{F(k)\phi(k)\phi^T(k)F(k)}{1+\phi^T(k)F(k)\phi(k)},\forall k\in N$$

$$\varepsilon^0(k+1)=y(k+1)-\hat{\theta}^T(k)\phi(t),\forall k\in N$$

$$F(0)=\frac{1}{\delta}I=(GI)I,0<\delta<1$$



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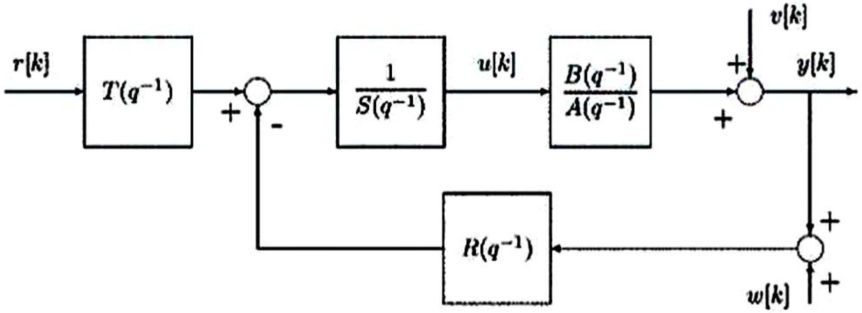
PROPOSED IDEA

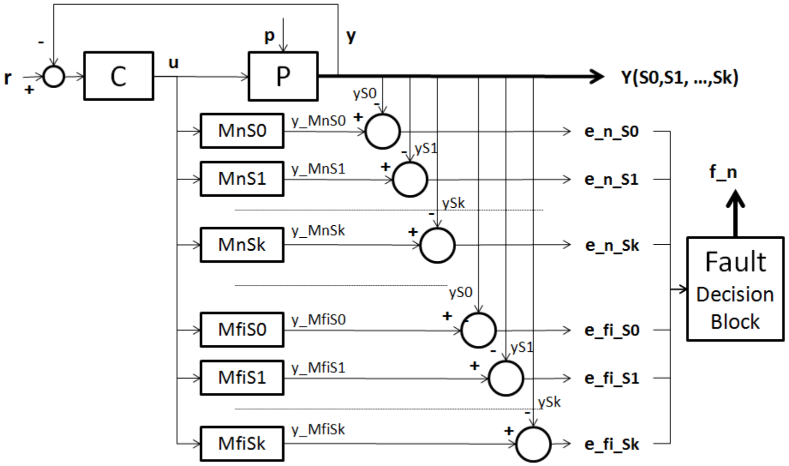
- **Control algorithm design –** based on identified models - since models may have high order the control algorithm is an RST type, with two degrees of freedom (poles placement design procedure).



$$R(q^{-1}) = r_0 + r_1 q^{-1} + \dots + r_{nR} q^{-nR}$$
$$S(q^{-1}) = s_0 + s_1 q^{-1} + \dots + s_{nS} q^{-nS}$$
$$T(q^{-1}) = t_0 + t_1 q^{-1} + \dots + t_{nT} q^{-nT}$$

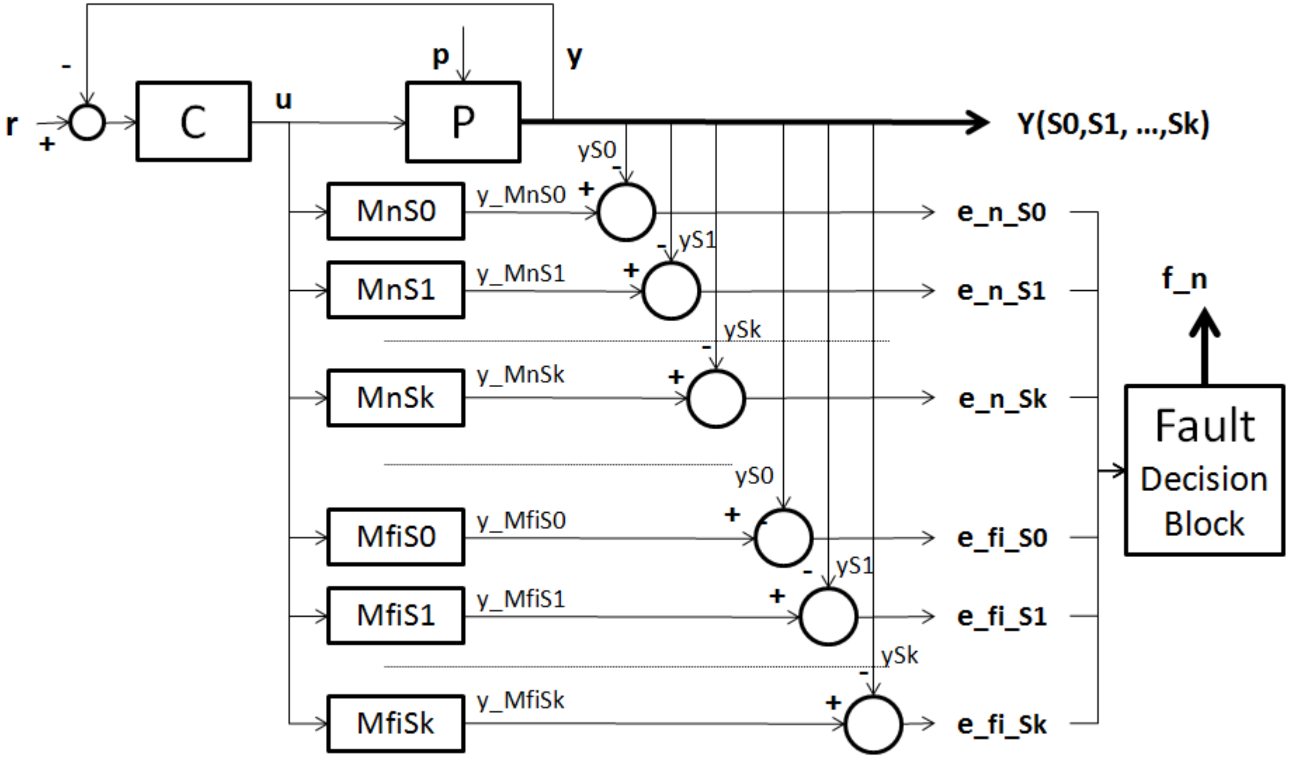
PROPOSED IDEA

- **Fault detection structure -** consists in using the identified models for control as well as for diagnosing the defects.
- The calculated command made by the control algorithm is applied in real time in process, as well as the models for normal functioning and the ones that describe the functioning affected by a defect.



PROPOSED IDEA

- **Fault detection structure**



PROPOSED IDEA

- **Fault detection procedure** - may include next steps:

•Verify models response: if N (N - normal) or, F11 or, respectively, F12 situation (F - fail), identified by the (minimal) corresponding model's error of the respective defects, a pre- identified fail was detected;

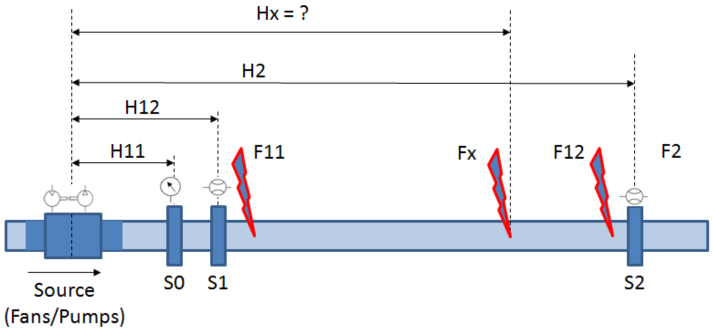
•If N error is high and simultaneously, F11 and F12 errors are small but, none is minimal, there is identified an *intermediary* fail *(with unknown position)*;

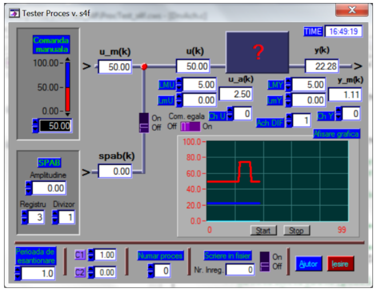
•Intermediary fail position (distance) is calculated based on real time values (computed control value (*u*) and S1 and S2 sensors data) and S1, S2 static characteristics value - calculated for corresponding actual control value). Distance ratio between F11 and F12 is calculated for each S1, S2 sensor and, the finally value, represents the mean of them. There is obtained a x% ratio between S1 and S2;

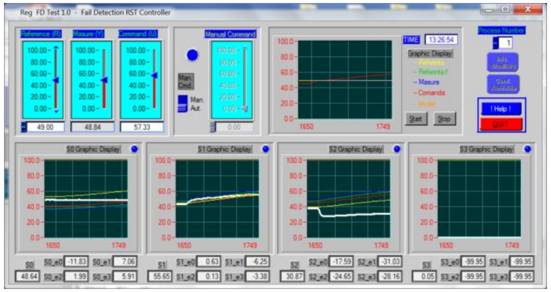
EXPERIMENTAL RESULTS

- **Real time tests:**

Some real time software applications and (real) experimental laboratory stand have been developed in order to implement and prove proposed solutions



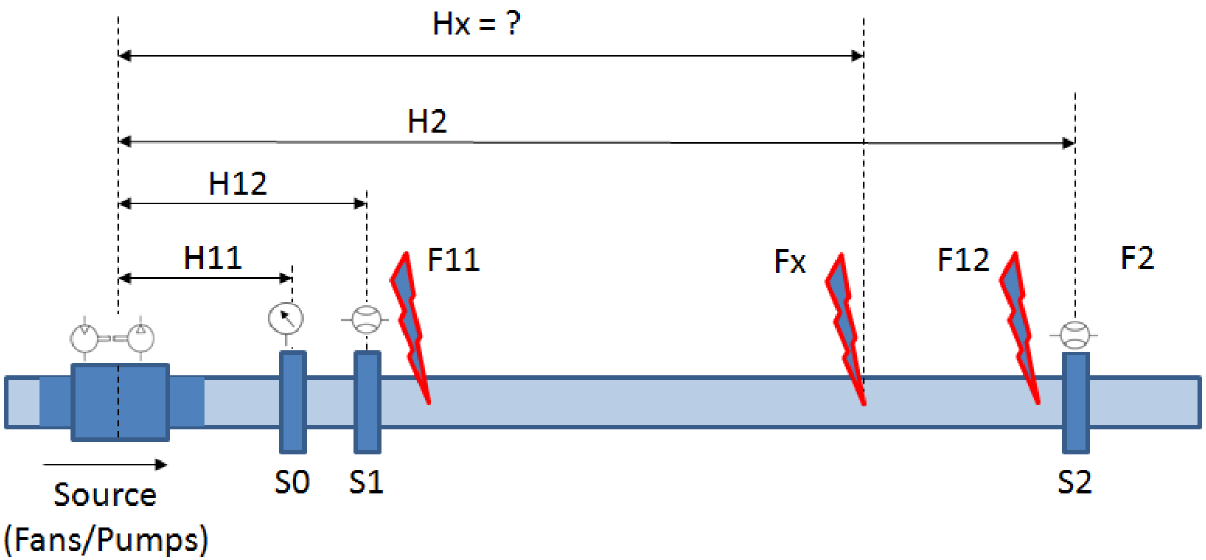




EXPERIMENTAL RESULTS

- **Experimental platform:**

contains one pressure (P), two flow sensors (S) and two axial fans arranged in series (as source)

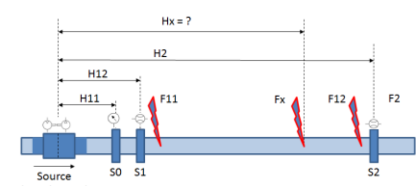


EXPERIMENTAL RESULTS

- **Real time tests:**

the effects of a fail can be visible in the data acquisition (from sensors). It is not mandatory for any fault to be "visible" by any sensor

Fail/ Sensor	F11 effect/(vary)	F1x effect/(vary)	F12 effect/(vary)
S0 pressure	constant	constant	constant
S1 flow	up / (high)	up / (medium)	up / (medium)
S2 flow	down / (medium)	down / (medium)	down / (medium)

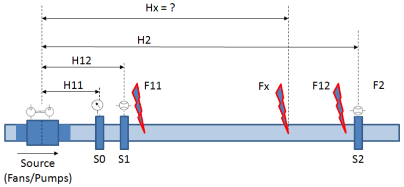


EXPERIMENTAL RESULTS

■ Real time evolutions:

The fails' effect, from the point of view of the operating points, for a imposed set point of S0=49.00% (with computed command for the first fan) and u2=20% for the second fan

Fail/ Sensor	Normal %	F11 %	F1x %	F12 %
u1 (for S0=49.00%)	47.00 %	66.00 %	62.00 %	60.00 %
S1 (flow)	44.00 %	80.00 %	54.00 %	56.00 %
S2 (flow)	38.00 %	34.12 %	34.73 %	35.45 %



EXPERIMENTAL RESULTS

Real time evolutions:

Corresponding models for normal (no fault) functioning and, (e.g.) the models for F11, F12 fault functioning for S0 sensor are (WinPIM) :

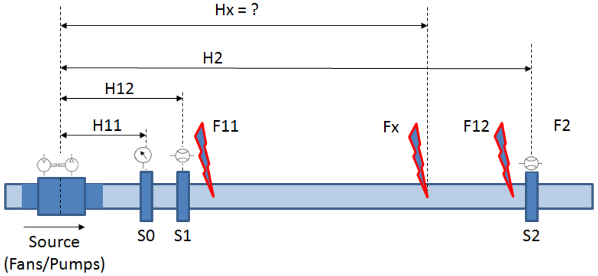
$$M_{S0n}(q^{-1}) = \frac{0.01977}{1-0.98297q^{-1}}$$

$$M_{S0f11}(q^{-1}) = \frac{0.01612}{1-0.97954q^{-1}}$$

$$M_{S1n}(q^{-1}) = \frac{0.00985+0.04696q^{-1}}{1-1.20647q^{-1}+0.26457q^{-2}}$$

$$M_{S0f12}(q^{-1}) = \frac{0.01752}{1-0.98023q^{-1}}$$

$$M_{S2n}(q^{-1}) = \frac{0.00915+0.03357q^{-1}}{1-1.16366q^{-1}+0.21295q^{-2}}$$

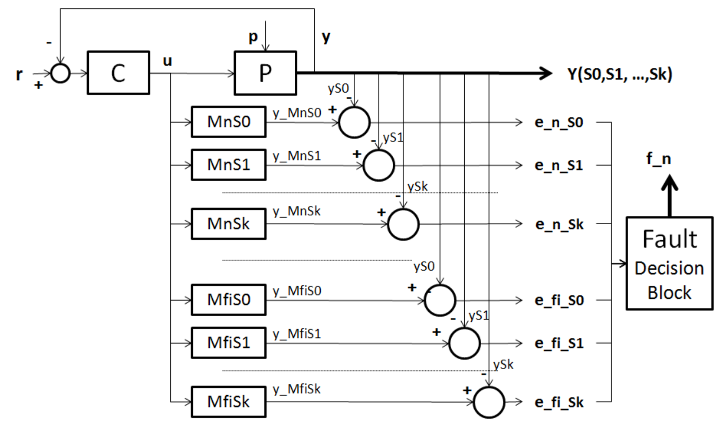


EXPERIMENTAL RESULTS

Real time evolutions:

The RST control algorithm for pressure (using S0 sensor) (WinREG) :

$$M_{S0n}(q^{-1}) = \frac{0.01977}{1-0.98297q^{-1}}$$

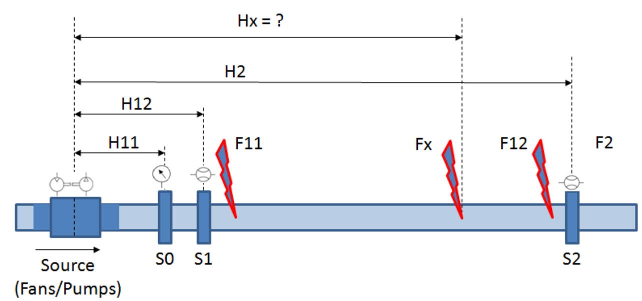


$$R(q^{-1}) = 29.116591 - 23.155438q^{-1}$$

$$S(q^{-1}) = 1.0 - 1.0q^{-1}$$

$$T(q^{-1}) = 50.581689 - 71.185382q^{-1} + 26.564846q^{-2}$$

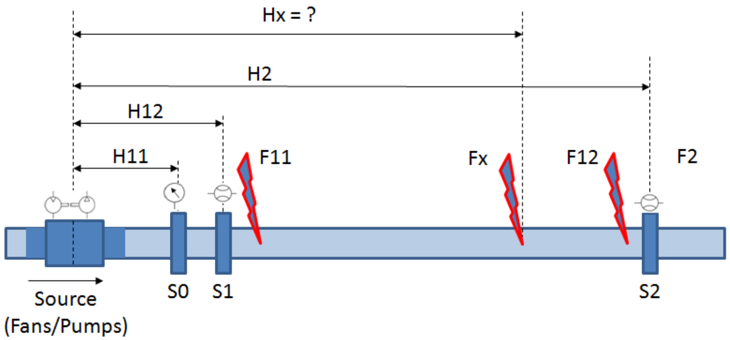
!!!



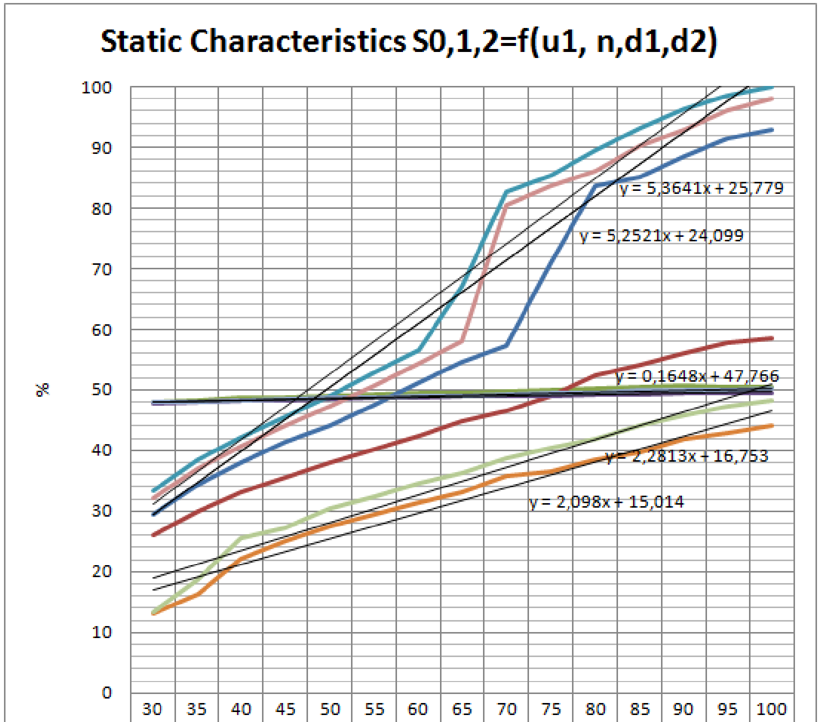
EXPERIMENTAL RESULTS

Real time evolutions:

Static characteristics (SC) for S0, S1 and S2 sensors



•Intermediary fail position (distance) is calculated based on real time values (computed control value (*u*) and S1 and S2 sensors data) and S1, S2 static characteristics value (calculated for corresponding actual control value). Distance ratio between F11 and F12 is calculated for each S1, S2 sensor and, the finally value, represents the mean of them. There is obtained a x% ratio between S1 and S2;

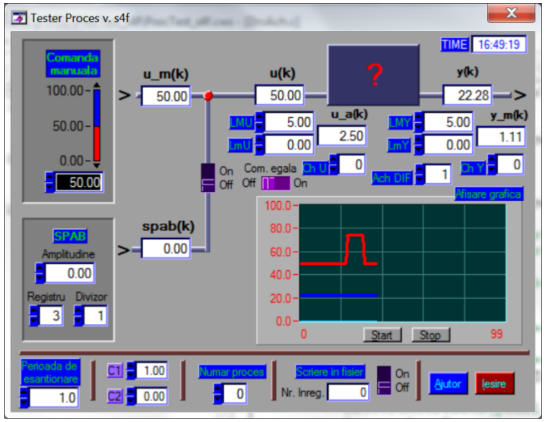


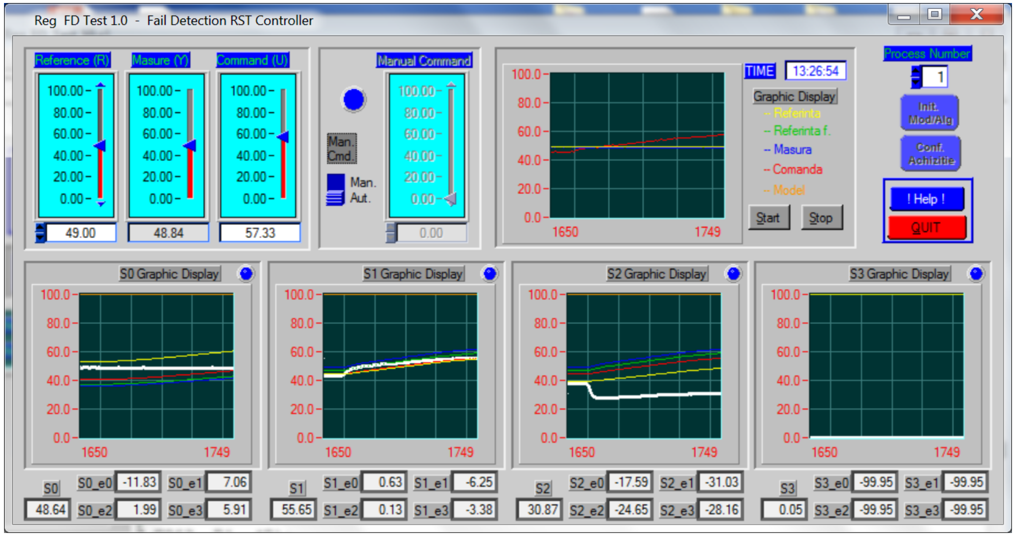
	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100
S0n	48	48,2	48,6	48,7	49,1	49,2	49,4	49,5	49,7	50	50,2	50,4	50,6	50,5	50,5
S1n	29,4	34,4	37,9	41,4	44	47,4	51,1	54,5	57,2	71	83,5	85	88,5	91,5	93
S2n	26	30,1	33	35,7	37,9	40,2	42,4	44,7	46,4	49	52,4	54	56	57,7	58,5
S0d1	47,8	48	48,1	48,3	48,5	48,6	48,7	48,9	49	49	49,2	49,3	49,4	49,5	49,6
S1d1	33,3	38,5	42,2	45,5	49	52,8	56,5	67	82,7	85,3	89,5	93,2	96,4	98,6	100
S2d1	13,1	16,2	22,1	25	27,4	29,4	31,4	33,1	35,8	36,5	38,4	39,6	41,9	43	44,2
S0d2	47,9	48	48,2	48,5	48,6	48,7	48,9	49	49,2	49,5	49,6	49,9	50	50,1	50,2
S1d2	32,1	36,9	40,6	44,1	47,3	50,7	54,4	58	80,6	83,7	86	90,3	93	96	98
S2d2	13,3	18,8	25,5	27,2	30,5	32,5	34,6	36,4	38,7	40,4	42	44	45,8	47,2	48,3

EXPERIMENTAL RESULTS

- **Real time evolutions:**

Real time software applications:

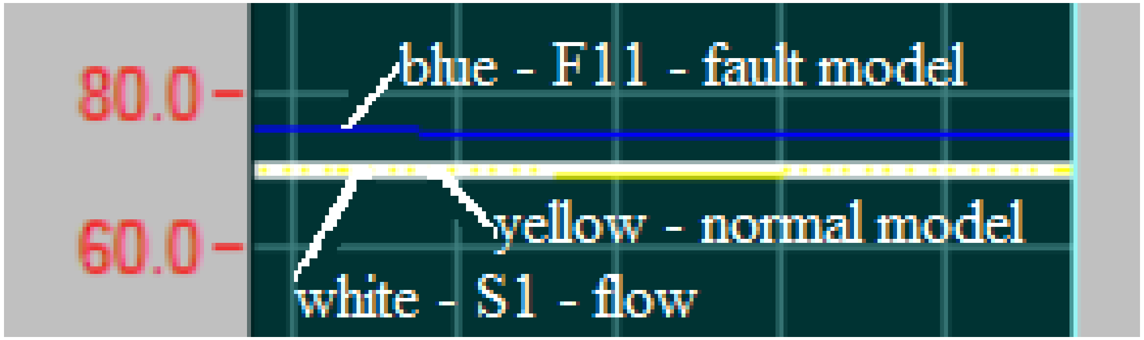


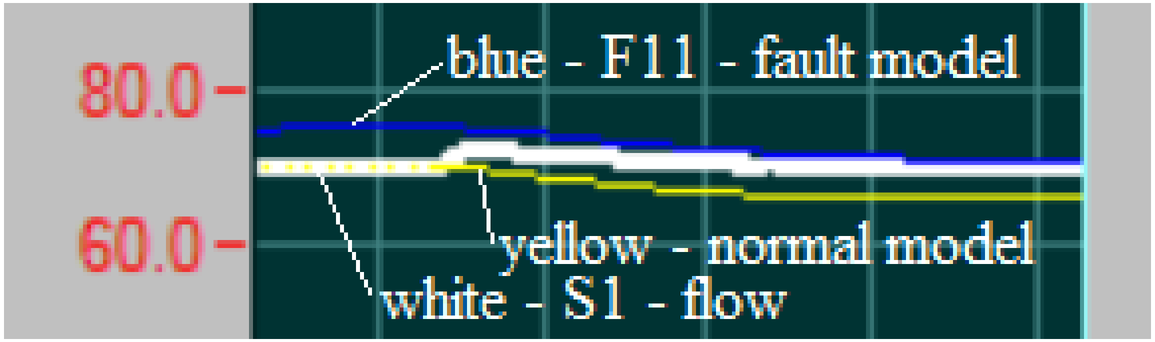


EXPERIMENTAL RESULTS

- **Real time evolutions:**

Normal functioning (up) vs. fault detection (down)





EXPERIMENTAL RESULTS

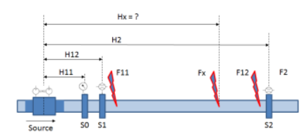
Real time evolutions:

An ”unknown” position fail (60% close to F11 and respectively, 40% close to F12) was caused. The corresponding control algorithm output is 63% and for S1 = 54% and S2 = 34.73% values ware read. From static characteristics (SC), corresponding distance relative to F11 and F12 ware (graphically) determinate.

Dist to S1 = Delta F11/(Delta F11+Delta F12)

Fail/ Sensor	Real time	F11 SC Pos [%]	F12 SC Pos [%]	Delta F11	Delta F12	Dist. To S1 [%]
S1 flow	54%	67%	58.00%	13%	4%	76%
S2 flow	34.73%	33.10%	36.36%	1.65%	1.65%	50%
Mean val.						63.2%

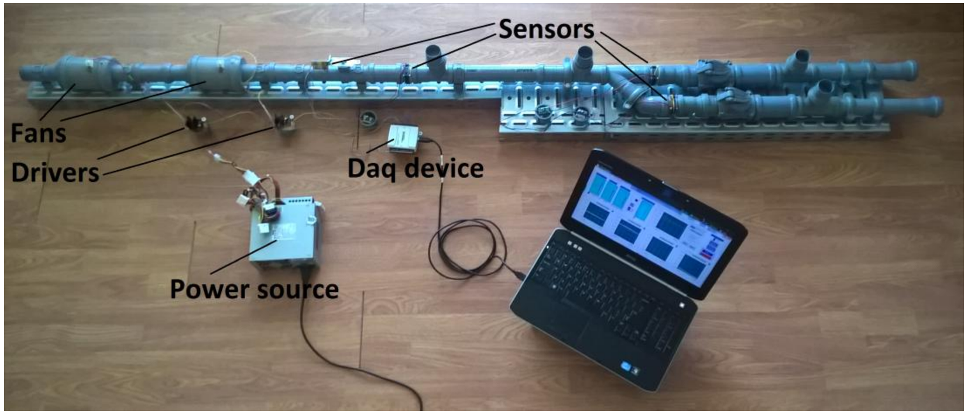
3.2% !!!



EXPERIMENTAL RESULTS

- Experimental platform

2 fans, 3 sensors, NI data acquisition system, NI CVI software



CONCLUSIONS and future steps

- **A practical solution** for fail/leak detection in distribution pipeline has been implemented by a **multidisciplinary team**;
- The proposed solution has some software and hardware components;
- Additive flow/pressure sensors need to be optimized and installed on each important section, and, of course, a corresponding communication network, too.
- Several research topics for Bachelor, Master, PhD theses ware proposed.

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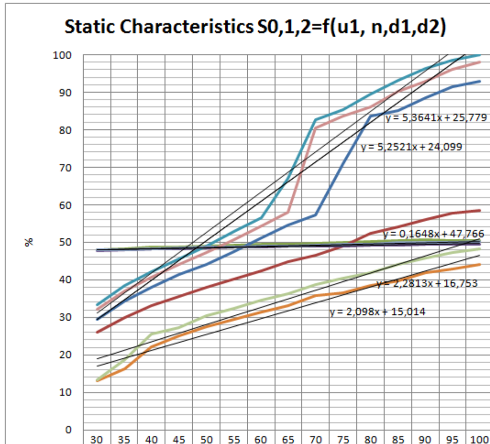
Thank you!

Consideration on real time implementation of leak/fault detection systems in mass transfer networks



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S0d1	47,8	48	48,1	48,3	48,5	48,6	48,7	48,9	49	49	49,2	49,3	49,4	49,5	49,6
S1d1	33,3	38,5	42,2	45,5	49	52,8	56,5	67	82,7	85,3	89,5	93,2	96,4	98,6	100
S2d1	13,1	16,2	22,1	25	27,4	29,4	31,4	33,1	35,8	36,5	38,4	39,6	41,9	43	44,2
S0d2	47,9	48	48,2	48,5	48,6	48,7	48,9	49	49,2	49,5	49,6	49,9	50	50,1	50,2
S1d2	32,1	36,9	40,6	44,1	47,3	50,7	54,4	58	80,6	83,7	86	90,3	93	96	98
S2d2	13,3	18,8	25,5	27,2	30,5	32,5	34,6	36,4	38,7	40,4	42	44	45,8	47,2	48,3

"Sometimes a clearly defined error is the only way to discover the truth"