ONLINE FUZZY TEMPORAL OPERATORS FOR COMPLEX SYSTEM MONITORING

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MOTIVATION

- **System monitoring and predictive maintenance**
  - Detect changes in exploitation in order to prevent damages

- **How ?**
  - Sensors and detectors provide information flows :
    - Data streams
    - Event streams

  - Theses streams are processed in order to get higher level of information

    ↓

    online gathering, filtering and combining data

- **Hypotheses with the sensor network**
  - Correct timestamps
  - Fuzzy logic → sensors inaccuracy + knowledge vagueness

INTRODUCTION

- **Develop an online fuzzy expert system (FES)**
  - Is able to process information flows
  - Is able to evaluate more complex relations : temporal, spatial, spatio-temporal relations, …
  - Provides fuzzy rules with more expressivity

- **Edition of vocabulary and rules**
  - Our FES is installed to our partner systems
  - Our partners must be able to edit the rule bases (not mathematician, not computer scientists, not engineers)

  → Touch interface for guided authoring of rules

- **Today : Temporal operators for complex system monitoring**

OUTLINE

- **Previous work**
- **Signal Characterization Operators**
  - Growth, decline, variation
  - Comparison
- **Application to a drift detection**
- **Conclusion & Perspectives**

PREVIOUS WORK : BASE OPERATORS (1)

- **Compositional paradigm : New temporal operators are derived from base operators [FuzzIEEE 2016]**
  - **Occurrence** : Something occurs if it is observed at least one moment in the fuzzy temporal scope

$$Occ(E, S, t_{now}) = \bigvee_{t \in supp(S)} eval(E, t) \wedge \mu_S(t)$$

the phenomenon   the scope   simply a weighted existence quantifier

  - **Ratio**
    Amount of time something happened during the scope

$$Ratio(E, S, t_{now}) = \frac{\int_{t \in supp(S)} eval(E, t) \wedge \mu_S(t)}{\int_{t \in supp(S)} \mu_S(t)}$$

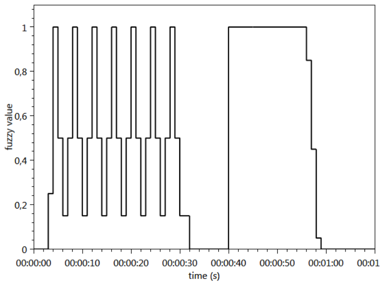
PREVIOUS WORK : EXAMPLE (2)

- Occurrence:

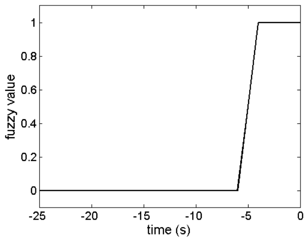
  (The temperature is high) OCCURED in the last 5/10 seconds

- Ratio :

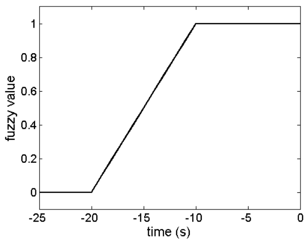
  Ratio of (The temperature is high) over the last 5/10 seconds



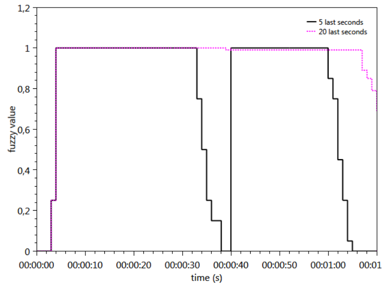
Temperature is high



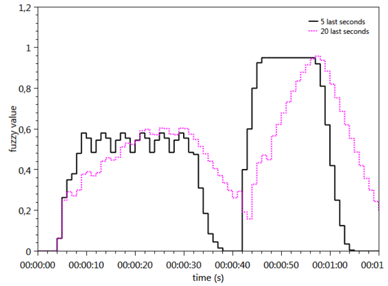
The last 5 seconds



The last 10 seconds



Temperature has been high in the last 5 / 10 seconds



Temperature has often been high in the last 5 / 10 seconds

PREVIOUS WORK (3)

- **Specificity of temporal base operators : they are able to expire to tell that they must be re-evaluated**

- **Why ?**
  - Data or event streams → Irregular arrivals; disruption of information flow.
  - Output values are given on the fly.

- **Last operator : Persistence**
  - A phenomenon persists if its negation never occurs

$$Pers(E, S, t_{now}) = \neg Occ(\neg E, S, t_{now})$$

SIGNAL CHARACTERIZATION OPERATORS (1)

- **What do we need to characterize signals in case of predictive maintenance ?**
  - Trend of a time-series : Growth, Decline and Variation
  - Comparison of two of them

- **These operators are build upon the Ratio operator :**
  - Tolerant behavior : if the input signal is changing for a short while, the direct effect of its change is smoothed.
  - If we need a strict behavior, we can use the Persistence operator.

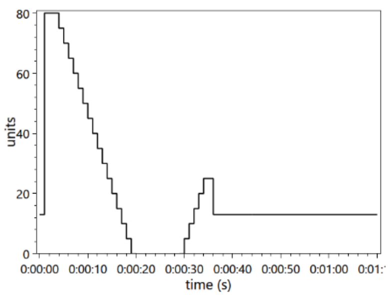
SIGNAL CHARACTERIZATION OPERATORS (2)

- **Analysis of trends in a time-series : Growth and decline**

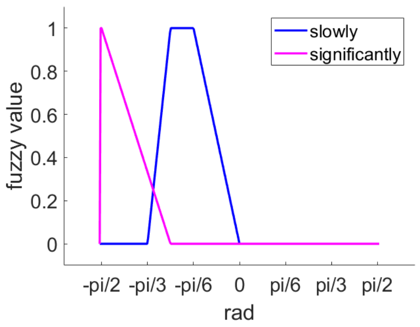
$$input \ \langle adverb \rangle \ \text{decreases/increases throughout} \ S.$$

$$Decreases(I, S, \mu_g, t_{now}) = Ratio(\mu_g(grad(I, t_{now})), S, t_{now})$$

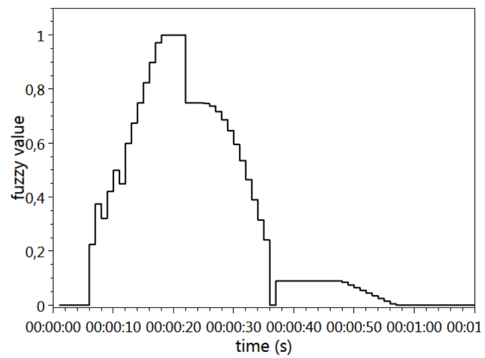
Based on the qualification of the gradient of two successive values over S



Signal of Input 1



Characterization of a decline



Input 1 significantly decreases throughout the last 10 seconds

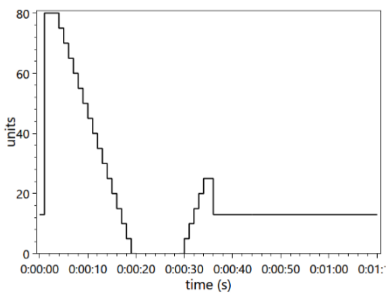
SIGNAL CHARACTERIZATION OPERATORS (3)

- **Analysis of stability in a time-series**
  - Variation : does the signal variate or is it stable ?

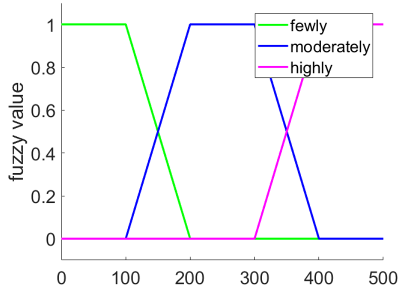
$$\text{input varies } \langle \textit{adverb} \rangle \text{ throughout } S$$

$$Varies(I, S, \mu_v, t_{now}) = \boxed{Ratio(\mu_v(\boxed{Var(I, supp(S))}), S, t_{now})}$$

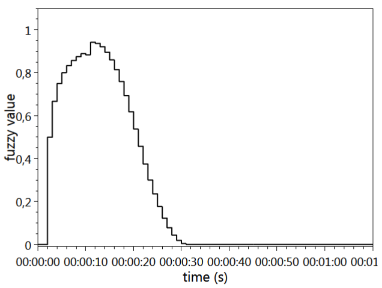
Based on the qualification of the variance of I during S



Signal of Input 1



Characterization of a variation



Input 1 varies significantly throughout the last 10 seconds

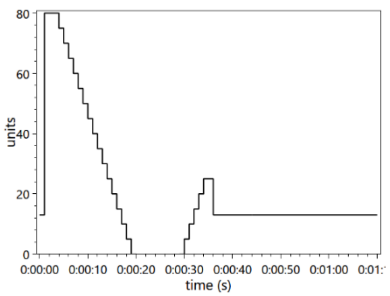
SIGNAL CHARACTERIZATION OPERATORS (4)

- **Comparison of two time-series : which of them is above, below, …**

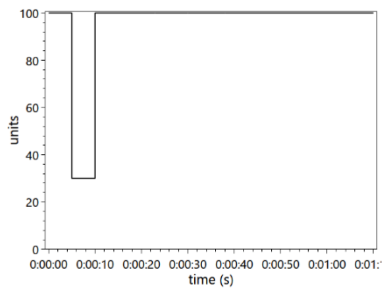
input1 is ⟨*adverb*⟩ less/greater/close than/to input2 throughout S.

$$GreaterThan(I_1, I_2, S, \mu_{gt}, t_{now}) = Ratio(\mu_{gt}(I_1(t_{now}) - I_2(t_{now})), S, t_{now}) \quad (7)$$

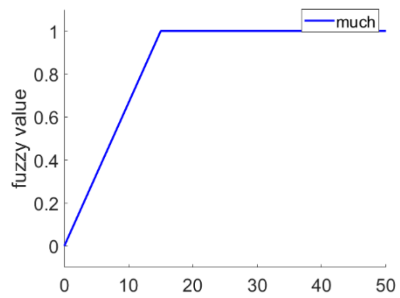
Based on the qualification of the difference of the two signals over S



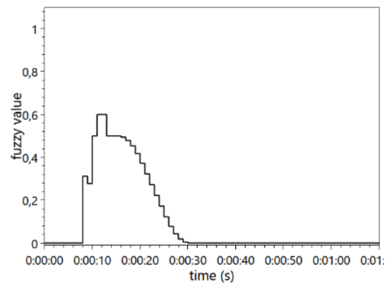
Signal of Input 1



Signal of Input 2



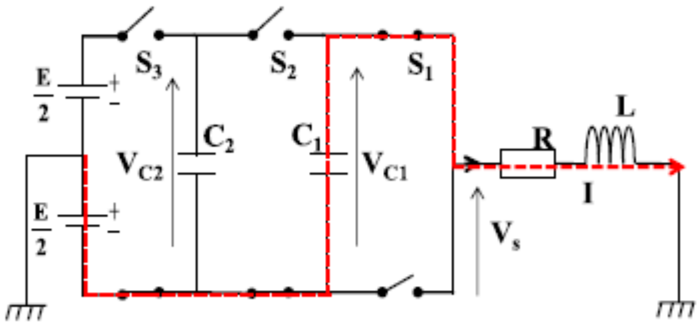
Characterization of the difference : much greater than



Input 1 is much greater than input 2 throughout the last 10 seconds

APPLICATION TO A DRIFT DETECTION (1)

- **Characterization of one sub-system of a wind turbine : a rotor-side multicellular converter (MCC).**
  - 1st subsystem according to the failure rate / turbine / year criterion
  - 2nd subsystem according to downtime / turbine / year criterion



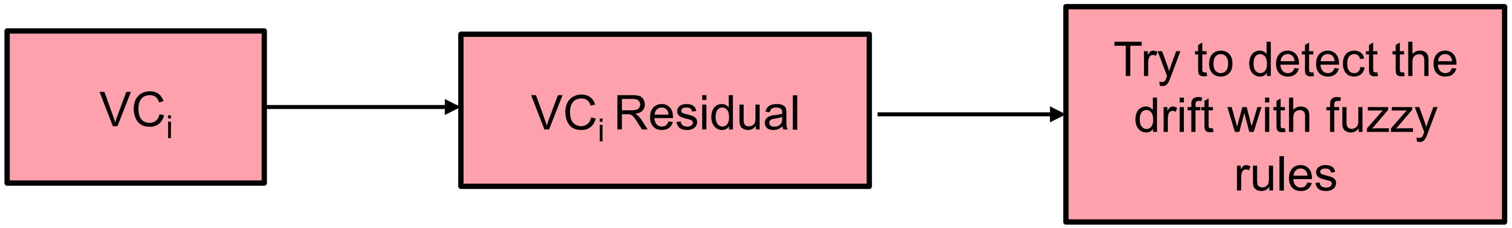
$$q_2 = (q_2^1 \; q_2^2 \; q_2^3), \text{with } h_{q_2} = (1 \;\; 0 \;\; 0)$$

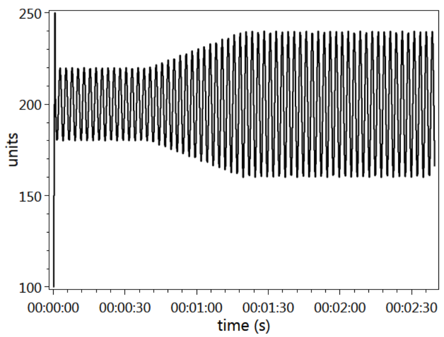
- **VC_i : floating voltage of the converter C_i may suffer from drifts.**
- **They can be detected or not according to the mode of the MCC that depends on the values of each cell.**

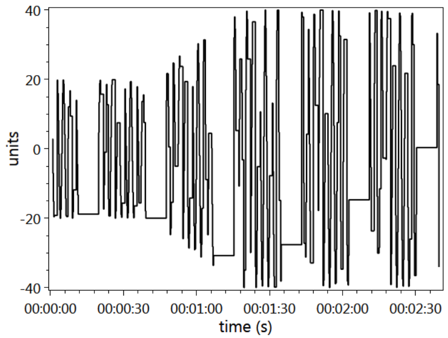
Toubakh H. and Sayed-Moudchaweh, Neurocomputing 2015

APPLICATION TO A DRIFT DETECTION (2)

- **Process overview:**



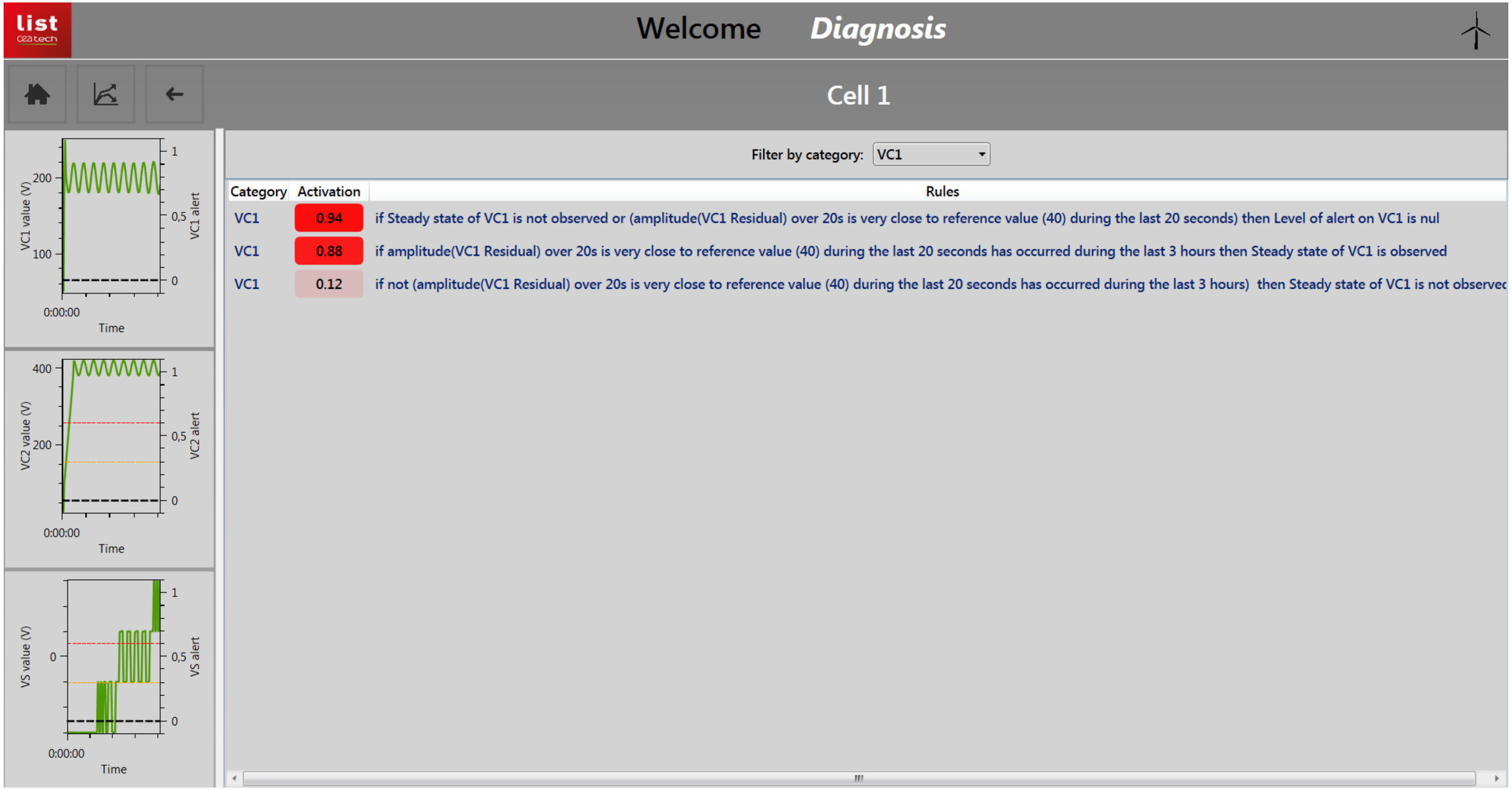




Simulated signal with a drift

- **Rules to establish that a steady state has been observed**
- **Rules to establish whether the observed signal is close to the expected value or not**

APPLICATION TO A DRIFT DETECTION (3)

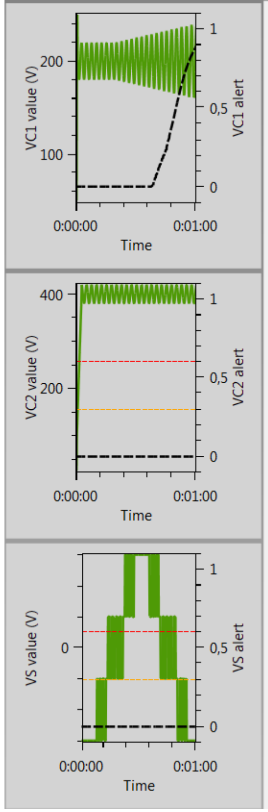


Category	Activation	Rules
VC1	0.94	if Steady state of VC1 is not observed or (amplitude(VC1 Residual) over 20s is very close to reference value (40) during the last 20 seconds) then Level of alert on VC1 is nul
VC1	0.88	if amplitude(VC1 Residual) over 20s is very close to reference value (40) during the last 20 seconds has occurred during the last 3 hours then Steady state of VC1 is observed
VC1	0.12	if not (amplitude(VC1 Residual) over 20s is very close to reference value (40) during the last 20 seconds has occurred during the last 3 hours) then Steady state of VC1 is not observed

APPLICATION TO A DRIFT DETECTION (3)

Welcome ***Diagnosis***

Cell 1



Filter by category: VC1

Category	Activation	Rules
VC1	1	if amplitude(VC1 Residual) over 20s is very close to reference value (40) during the last 20 seconds has occurred during the last 3 hours then Steady state of VC1 is observed
VC1	0.87	if Steady state of VC1 is observed and (amplitude(VC1 Residual) over 20s is much higher than reference value (40) during the last 20 seconds) then Level of alert on VC1 is high
VC1	0.21	if Steady state of VC1 is observed and (amplitude(VC1 Residual) over 20s is slightly higher than reference value (40) during the last 20 seconds) then Level of alert on VC1 is low
VC1	0	if Steady state of VC1 is not observed or (amplitude(VC1 Residual) over 20s is very close to reference value (40) during the last 20 seconds) then Level of alert on VC1 is nul

CONCLUSION AND FUTURE WORK

- **Compositional paradigm to create new temporal operators to characterize the kinetics of input values**
- **Experts can describe their knowledge about the system with fuzzy rules even if they are not mathematicians**
- **Justification of decisions made thank to activated rules**
- **Formalization of new operators in different domains :**
  - Times-series characterization
  - Spatial and spatio-temporal information characterization

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APPLICATION TO A DRIFT DETECTION (2)

- **Process overview:**

VC_i → VC_i Residual → Try to detect the drift with fuzzy rules