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First Flush Harvesting Application With Fuzzy Logic

Authors: *Georgia Atsali, Spyros Panagiotakis, Dimitris Katrinakis, Michael Kalochristianakis, Thrasyvoulos Manios, Athanasios Malamos*

What is it about?

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- This paper presents a roof rainfall harvesting system, which uses fuzzy logic control to convert the direction of the rain runoff water, between two tanks.
- It is a part of a novel system called Holistic which was installed in a building complex here in Heraklion.
- The work was funded by the European Union and the Hellenic Ministry of Education and Religious Affairs under the "Program for the development of industrial research and technology 2013 - PAVET" research framework.

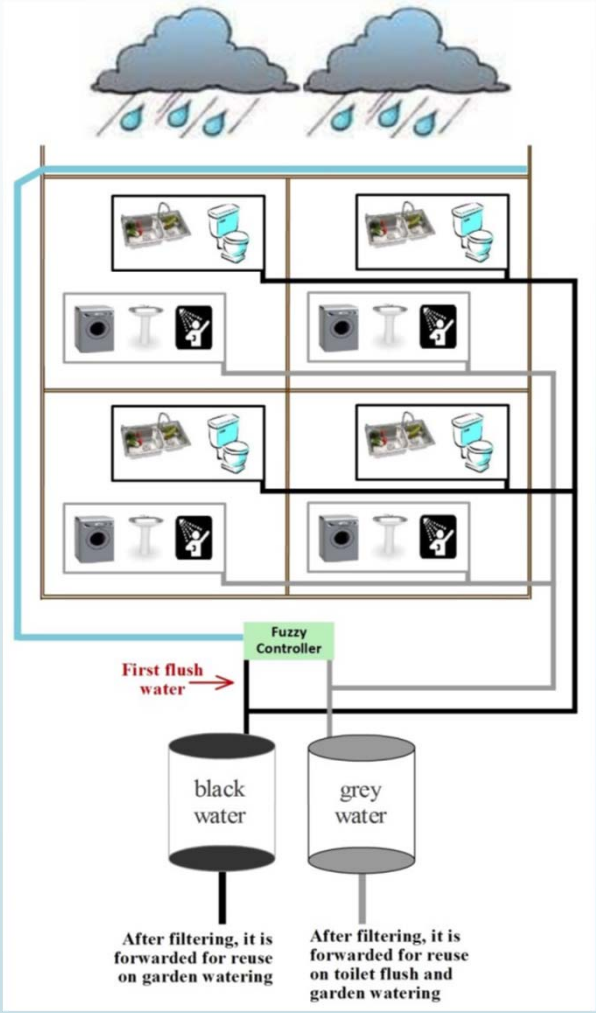
Holistic System

This system monitors, controls and manages the residential water infrastructure.

- **Harvests** all building water runoffs, into different water tanks grey and black, for processing.

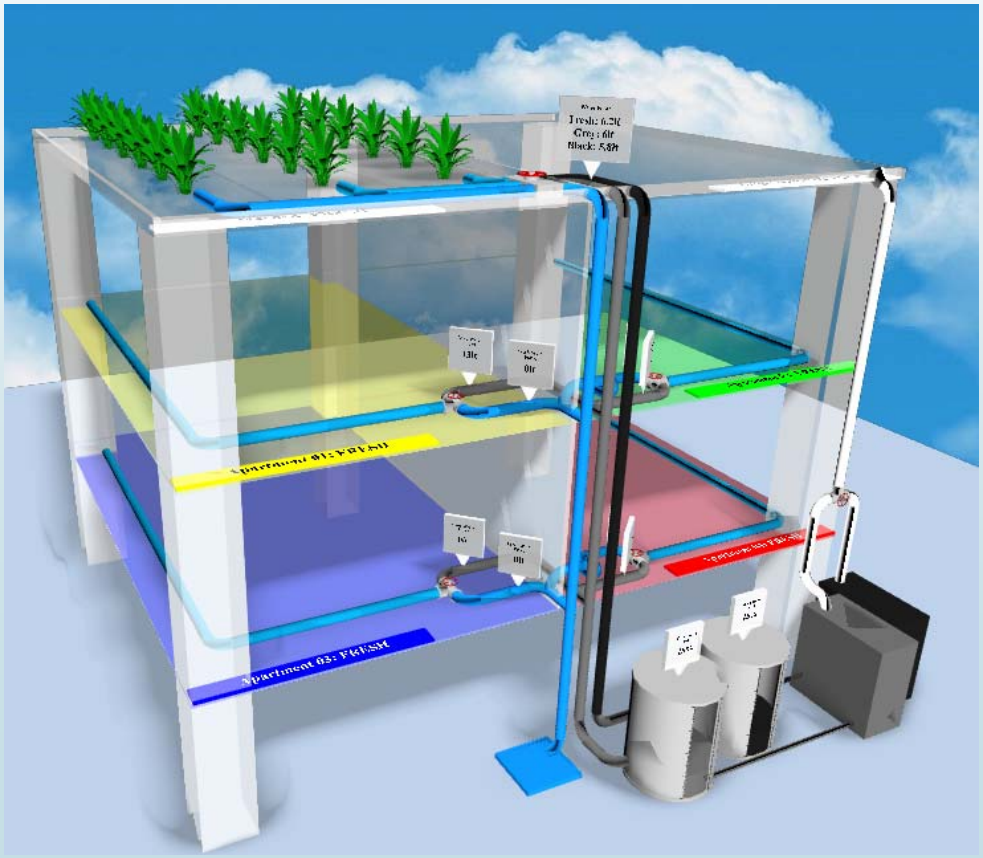
Harvesting water from:

- roof (black and grey water),
- sinks and toilets (black)
- showers/baths, washing machine (grey)



Holistic System

- **Distributes** the recycled water to apartments' toilet cisterns (grey) and to the roof garden watering system (grey and black).



Architecture

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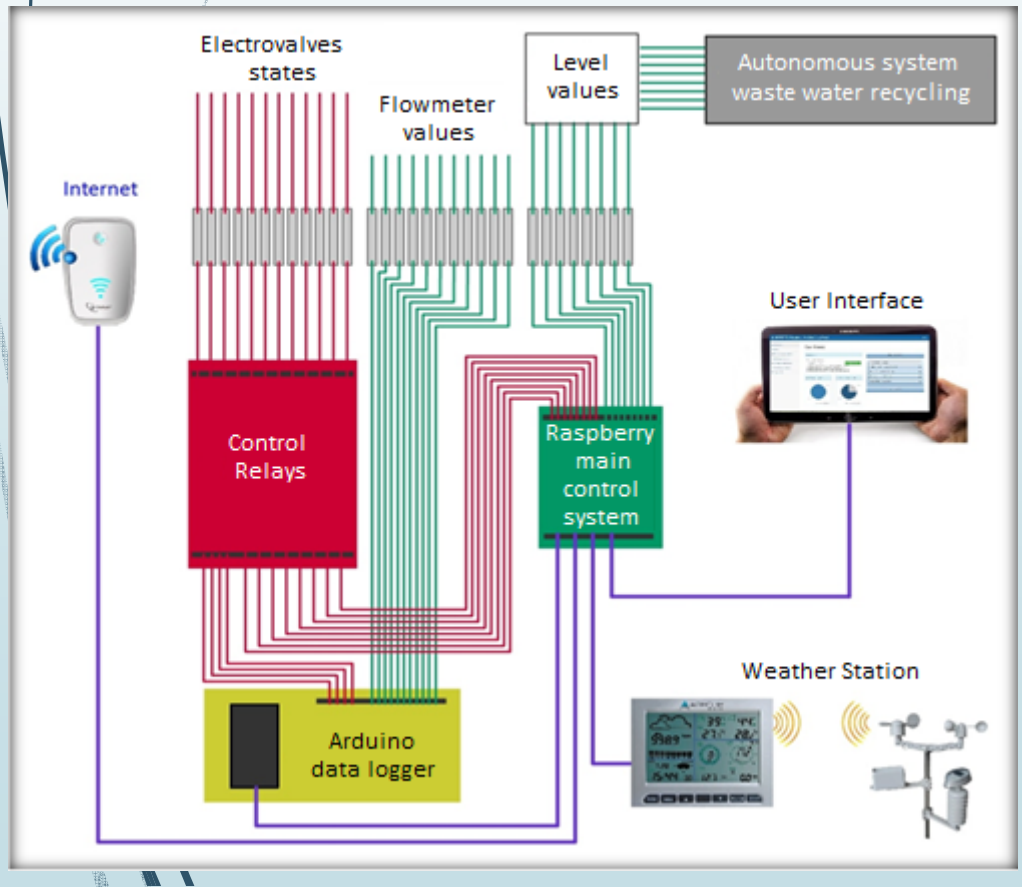
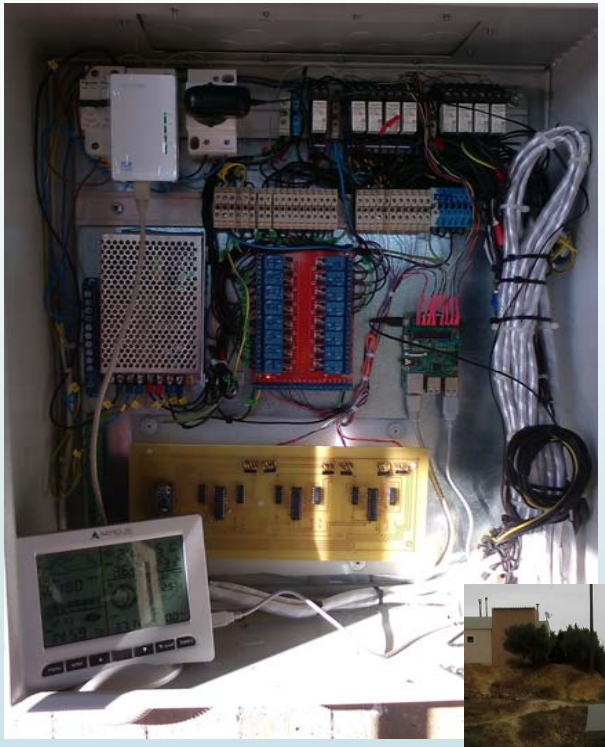
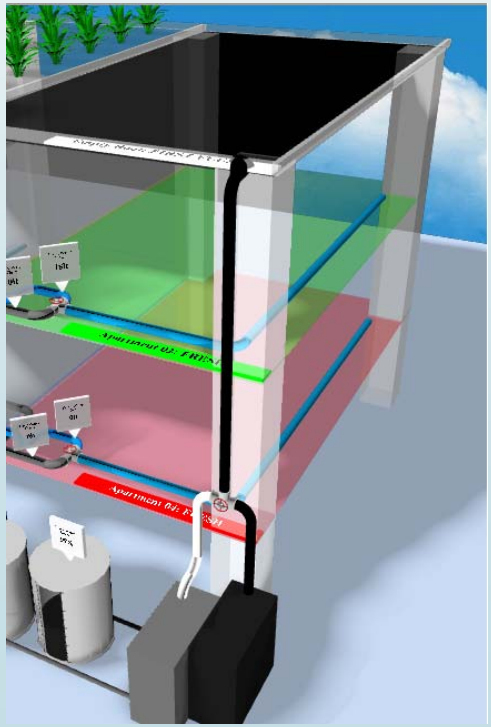
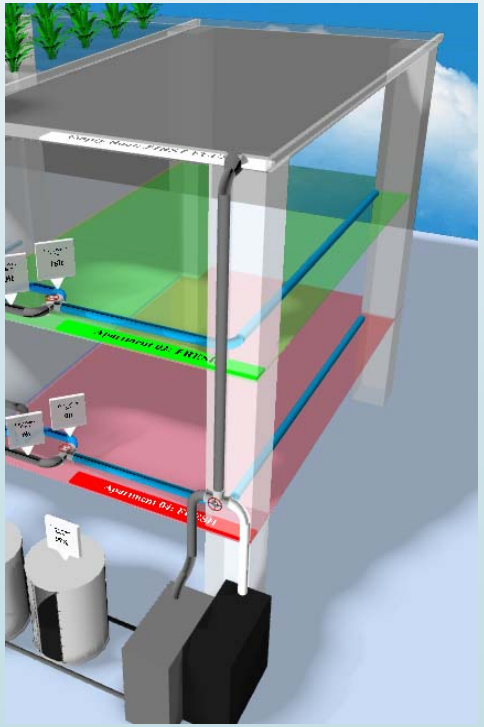




First Flush Concept

- The first water volume of a rainfall event contains larger concentrations of pollutants than the remainder water. The separation of the first and heavier in pollutants volume of water is described as the first flush event.





First Flush Model

Considering

- the surface features of the roof

  (e.g. length, material, location - near highway)

- and multiple chemical experiments performed, to determine the concentrations of heavy metals

a dataset was produced.

After studying this dataset a series of linguistic rules were created. The form of these rules is

*" **IF** the drought period is A days **and** the rainfall intensity is B mm/h **then** after X minutes of time the first flush ends."*

Fuzzy Logic

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- We designed a fuzzy logic controller to relate the linguistic rules with the first flush event.
- An important problem with first flush method is the need to cope with the large amount of uncertainty, which is inherent of natural environments. Fuzzy logic's features make it a suitable tool to address this problem

Fuzzy Controller Development

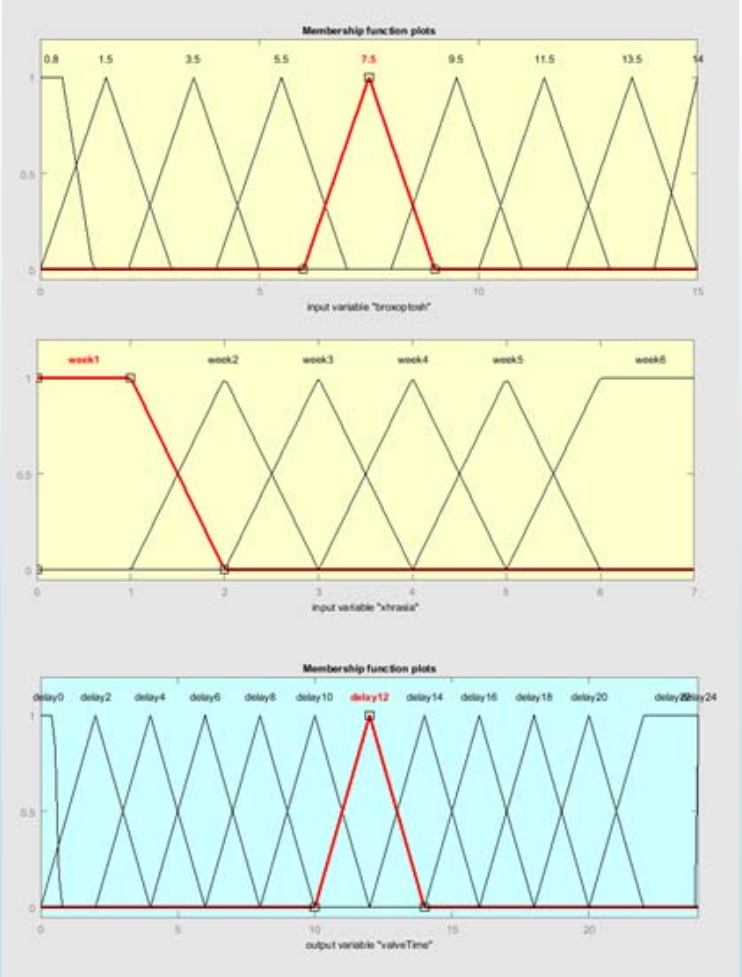
- The fuzzy logic controller consists of two inputs:

  - *the rainfall intensity*

  - *the drought period*

  and one output:

  - *the time needed for the first flush event to end.*

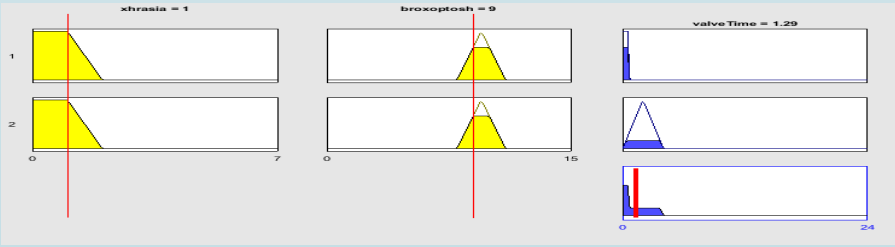


Fuzzy Controller Development

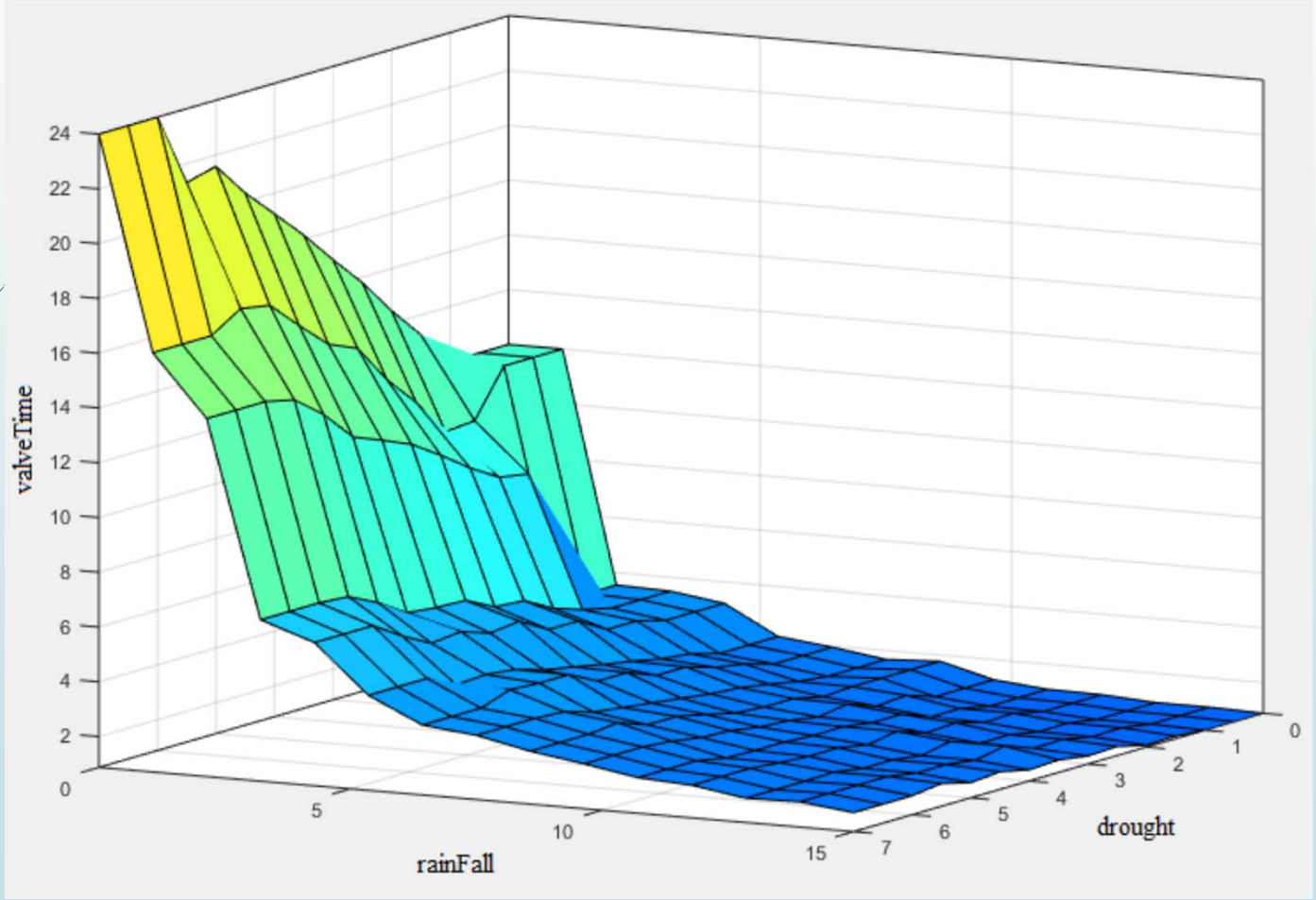
- The fuzzy controller also contains a set of linguistic rules which describes the dependencies between the inputs and the output.
- Depending on the input values one or more rules are triggered to calculate the time.

The selected defuzzification method is the center of gravity.

```
RULE : IF duration IS week1 AND rainFall IS I08  THEN valveTime IS delay14 WITH 1;
RULE : IF duration IS week1 AND rainFall IS I35  THEN valveTime IS delay6  WITH 0.35;
RULE : IF duration IS week1 AND rainFall IS I35  THEN valveTime IS delay2  WITH 1;
RULE : IF duration IS week1 AND rainFall IS I55  THEN valveTime IS delay2  WITH 1;
RULE : IF duration IS week1 AND rainFall IS I55  THEN valveTime IS delay4  WITH 0.07;
RULE : IF duration IS week1 AND rainFall IS I75  THEN valveTime IS delay0  WITH 1;
RULE : IF duration IS week1 AND rainFall IS I75  THEN valveTime IS delay4  WITH 0.1;
RULE : IF duration IS week1 AND rainFall IS I95  THEN valveTime IS delay0  WITH 1;
RULE : IF duration IS week1 AND rainFall IS I95  THEN valveTime IS delay2  WITH 0.25;
RULE : IF duration IS week1 AND rainFall IS I115 THEN valveTime IS delay0  WITH 1;
RULE : IF duration IS week1 AND rainFall IS I115 THEN valveTime IS delay2  WITH 0.15;
RULE : IF duration IS week1 AND rainFall IS I135 THEN valveTime IS delay0  WITH 1;
RULE : IF duration IS week1 AND rainFall IS I135 THEN valveTime IS delay2  WITH 0.11;
RULE : IF duration IS week1 AND rainFall IS I15  THEN valveTime IS delay8  WITH 1;
RULE : IF duration IS week1 AND rainFall IS I15  THEN valveTime IS delay12 WITH 0.2;
RULE : IF duration IS week2 AND rainFall IS I08  THEN valveTime IS delay14 WITH 1;
RULE : IF duration IS week2 AND rainFall IS I08  THEN valveTime IS delay16 WITH 0.2;
RULE : IF duration IS week2 AND rainFall IS I15  THEN valveTime IS delay8  WITH 1;
RULE : IF duration IS week2 AND rainFall IS I15  THEN valveTime IS delay12 WITH 0.44;
RULE : IF duration IS week2 AND rainFall IS I35  THEN valveTime IS delay4  WITH 1;
RULE : IF duration IS week2 AND rainFall IS I35  THEN valveTime IS delay6  WITH 0.04;
RULE : IF duration IS week2 AND rainFall IS I55  THEN valveTime IS delay2  WITH 1;
RULE : IF duration IS week2 AND rainFall IS I55  THEN valveTime IS delay6  WITH 0.099;
RULE : IF duration IS week2 AND rainFall IS I75  THEN valveTime IS delay2  WITH 1;
```



Fuzzy Controller Development



Fuzzy controller evaluation

- A complete run of the roof harvesting module is saved to each row in a dedicated table of the database.
- It starts when the rain starts and ends with the end of the rain.
- Between these two points all related data and events are also recorded to this row.

id	rainStarted	rain	drought	fftime	valveToGrey	rainStop	valveToBlack
546219	2016-02-11 12:29:56	5	5	2	2016-02-11 12:29:56	2016-02-11 12:29:56	2016-02-11 12:29:56
546222	2016-02-11 15:47:01	1.1	0	0.37	2016-02-11 15:47:38	2016-02-11 16:11:04	2016-02-11 16:11:04
546223	2016-02-15 06:21:07	2.5	3	1.9	2016-02-15 06:22:16	2016-02-15 06:41:10	2016-02-15 06:41:10
546224	2016-02-15 11:19:06	4.7	0	0.18	2016-02-15 11:19:24	2016-02-15 11:56:01	2016-02-15 11:56:02
546225	2016-09-16 13:41:11	1.7	1	1.21	NULL	2016-09-16 13:41:31	2016-09-16 13:41:31
546226	2016-09-18 17:19:27	3.7	3	1.43	2016-09-18 17:21:10	2016-09-18 17:58:17	2016-09-18 17:58:17

Conclusion

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- We developed a simplified Fuzzy Logic Controller that solves the problem of a First Flush Event in an efficient way.
- We choose Fuzzy Logic because
  - it is tolerant of imprecise data
  - it models the nonlinear functions of the first flush problem
  - it blended well with all the other control techniques
  - and its based on natural language rules.

The system is currently at the evaluation state and it response well.

Thank you