Fuzzy Controller Update

Development of the fuzzy controller based on the Fuzzy Control Language (FCL) standard has finally reached the first steps of being operational. Not integrated with the hse, and not finished yet.

At this point, the ability to parse a generic FCL file, create the data structures and values, read in a time-series of input data points, run the fuzzy control, and output a time-series of results for singleton outputs seems to be working. A singleton output is a fuzzy output variable that isn't a fuzzy set, it's just a x,y ouput. However, the fuzzification and rule-inferencing are the same.

Of course, there have been some 'enhancements' the FCL standard such as allowing // comments.

The following slides show:

1-2 The FCL file. This defines a system with two input variables, temp and pressure, and two output variables, valve1 and valve2. The FUZZIFY and DEFUZZIFY blocks are depicted in slide 3. Slide 2 shows the FCL rule base. A nice feature of fuzzy logic is that the rule base is formed from linguistic variables, so the rules should be understandable to anyone.

3 The fuzzy input terms, and the fuzzy output terms.

4 Results of running the controller. Top two graphs are input pressure and temp, bottom two are valve1 and valve2 outputs. It seems to follow the rule-base.

Next comes addition of fuzzy output sets, actually they are already created, it's a matter of handling the defuzzification for them. Testing of features. Interfacing into the hse.

It would be nice to have some hydrological rule-base test cases.

```
FUNCTION_BLOCK Fuzzy_FB
VAR_INPUT
      // temperature and pressure input variables
      temp    : REAL;
      pressure : REAL;
END_VAR
VAR_OUTPUT
      // dual valve output
      valve1 : REAL;
      valve2 : REAL;
END_VAR
FUZZIFY temp
      // cold ramp, warm trapezoid, hot ramp
      TERM cold := (30, 1) (50, 0);
      TERM warm := (30, 0) (40, 1) (60, 1) (70, 0);
      TERM hot  := (50, 0) (70, 1);
END_FUZZIFY
FUZZIFY pressure
      // ramp, triangle, trapezoid, triangle, ramp
      TERM low     := (200, 1) (400, 0);
      TERM med_low  := (200, 0) (400, 1) (600, 0);
      TERM medium   := (400, 0) (450, 1) (550, 1) (600, 0);
      TERM med_high := (400, 0) (600, 1) (800, 0);
      TERM high    := (600, 0) (800, 1);
END_FUZZIFY
DEFUZZIFY valve1
       // All outputs are singletons
       TERM closed         := 0;   // (0, 0) (10, 1);
       TERM quarter_open     := 25;  // (0, 0) (4, 1) (6, 1) (10, 0);
       TERM half_open        := 50;
       TERM threeQuarter_open := 75;
       TERM open              := 100;
       ACCU: MAX;
       METHOD: COG;
       DEFAULT:= 0;
       RANGE:= (0, 100);
END_DEFUZZIFY
DEFUZZIFY valve2
       // All outputs are singletons
       TERM closed        := 0;   // (0, 0) (10, 1);
       TERM quarter_open     := 25;  // (0, 0) (4, 1) (6, 1) (10, 0);
       TERM half_open        := 50;
       TERM threeQuarter_open := 75;
       TERM open              := 100;
       ACCU: MAX;
       METHOD: COG;
       DEFAULT:= 0;
       RANGE:= (0, 100);
END_DEFUZZIFY
```

```
RULEBLOCK No1
        AND : MIN;
        OR  : MAX;
        ACT : MIN;
        //
        RULE 1: IF temp IS cold AND pressure IS low
                THEN valve1 IS closed, valve2 IS open;
        //
        RULE 2: IF temp IS cold AND pressure IS med_low
                THEN valve1 IS quarter_open, valve2 IS threeQuarter_open;
        //
        RULE 3: IF temp IS cold AND pressure IS medium
                THEN valve1 IS half_open, valve2 IS half_open;
        //
        RULE 4: IF temp IS cold AND pressure IS med_high
                THEN valve1 IS threeQuarter_open, valve2 IS quarter_open;
        //
        RULE 5: IF temp IS cold AND pressure IS high
                THEN valve1 IS open, valve2 IS closed;
    //
        RULE 6: IF temp IS warm AND pressure IS low
                THEN valve1 IS quarter_open, valve2 IS threeQuarter_open;
        //
        RULE 7: IF temp IS warm AND pressure IS med_low
                THEN valve1 IS half_open, valve2 IS threeQuarter_open;
        //
        RULE 8: IF temp IS warm AND pressure IS medium
                THEN valve1 IS half_open, valve2 IS half_open;
        //
        RULE 9: IF temp IS warm AND pressure IS med_high
                THEN valve1 IS half_open, valve2 IS quarter_open;
        //
        RULE 10: IF temp IS warm AND pressure IS high
                 THEN valve1 IS threeQuarter_open, valve2 IS quarter_open;
        //
        RULE 11: IF temp IS hot AND pressure IS low
                 THEN valve1 IS open, valve2 IS closed;
        //
        RULE 12: IF temp IS hot AND pressure IS med_low
                 THEN valve1 IS threeQuarter_open, valve2 IS quarter_open;
        //
        RULE 13: IF temp IS hot AND pressure IS medium
                 THEN valve1 IS half_open, valve2 IS half_open;
        //
        RULE 14: IF temp IS hot AND pressure IS med_high
                 THEN valve1 IS quarter_open, valve2 IS threeQuarter_open;
        //
        RULE 15: IF temp IS hot AND pressure IS high
                 THEN valve1 IS closed, valve2 IS open;
END_RULEBLOCK
END_FUNCTION_BLOCK
```