



# FORMATION OF A TRAINING SIGNAL USING A GENETIC ALGORITHM IN THE TASK OF PRESSURE STABILIZATION IN A NITROGEN CRYOGENIC PLANT

U.G. Besimalov, **M.S. Katulin**, D.V. Neapolitansky,  
A.G. Reshetnikov, S.V.Ulyanov, P.V. Zrelov

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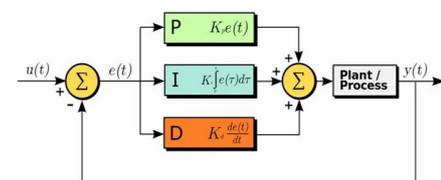
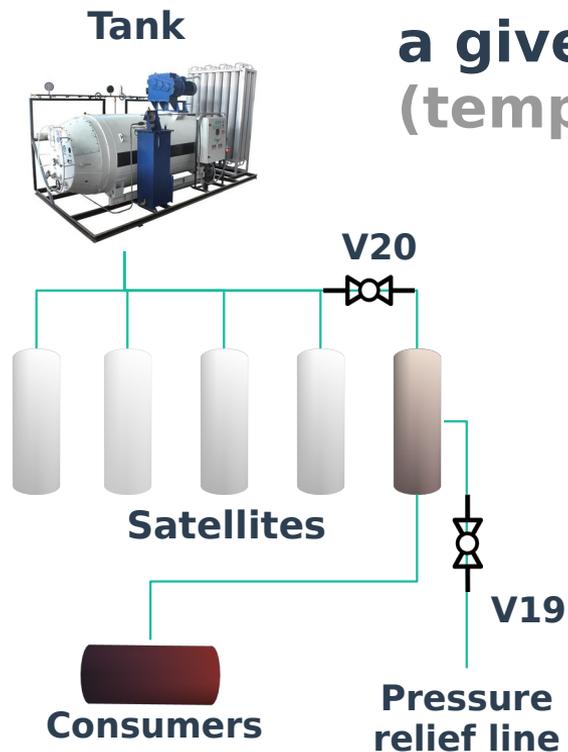
# Task description

## JINR magnet assembly and testing hall



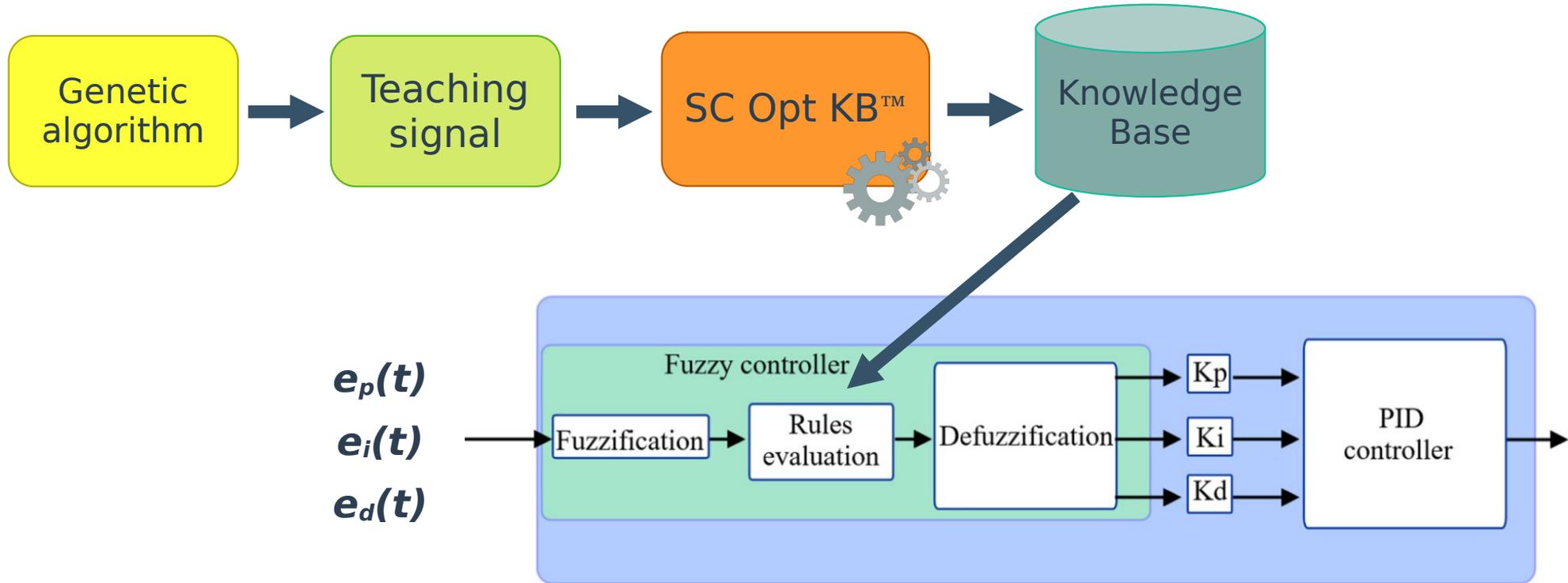
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<https://topblognews.ru/obshhestvo/mks-i-kollajder-nobelevskij-laureat-ting-rasskazal-o-svoih-eksperimentah/>

## The Goal is to keep a given pressure (temperature)



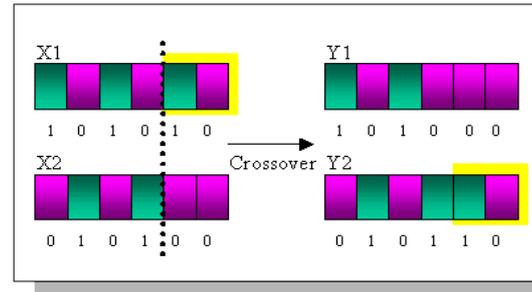
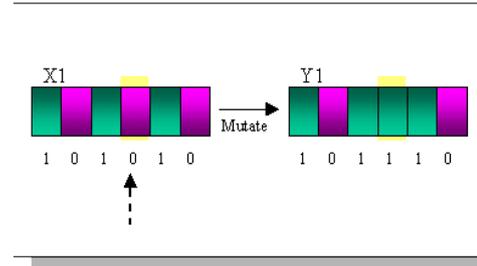
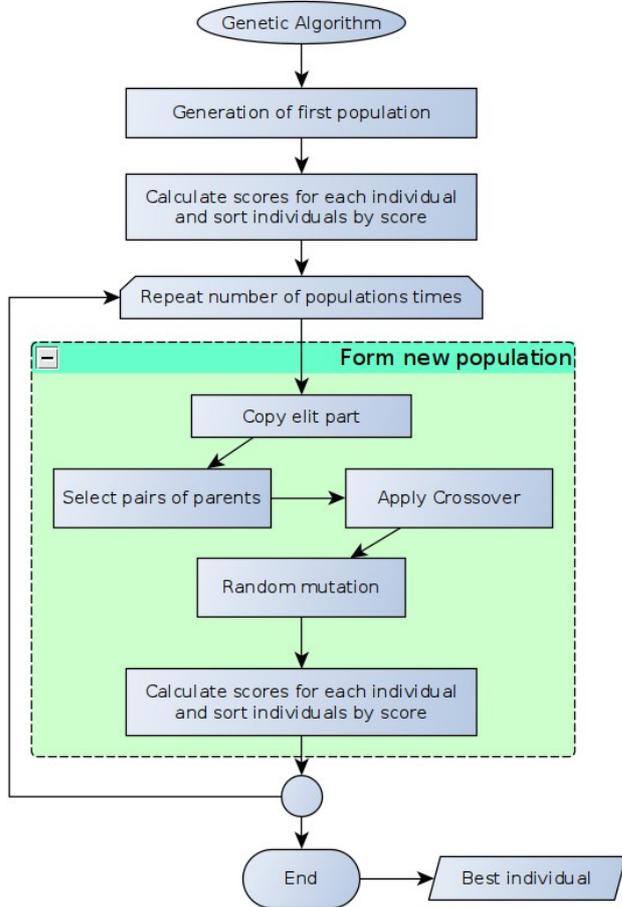
PID → FC → QFC

# Fuzzy controller



\* V.N. Zakharov, S.V.Ulyanov - Fuzzy models of intelligent industrial controllers and control systems // Journal of computer and Systems sciences international, 33(2), 1995. ISSN1064-2307/95/0002-0094

# Genetic Algorithm



- Search algorithm (launched once)
- Coefficients are encoded to bits
- Was launched on real object in real time

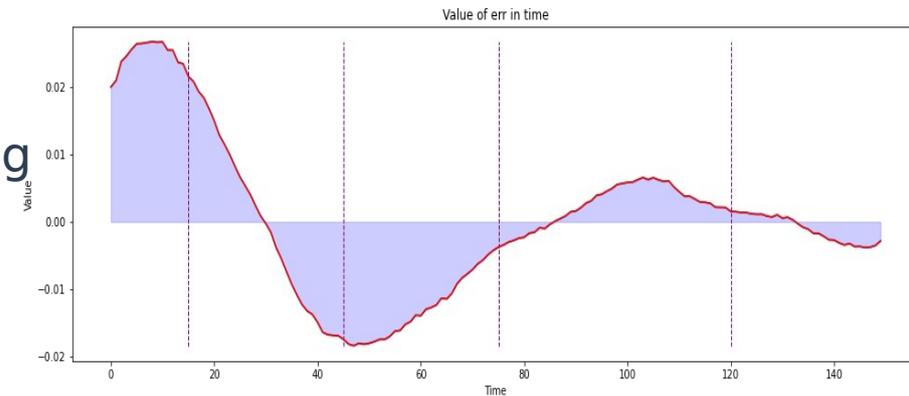
# Genetic Algorithm

## Fitness function:

- V19 opened for 20 seconds at the beginning
- 10 minutes of control with each decision
- $F = \sum_{i=0}^N |P_t - P_i| \rightarrow \min$

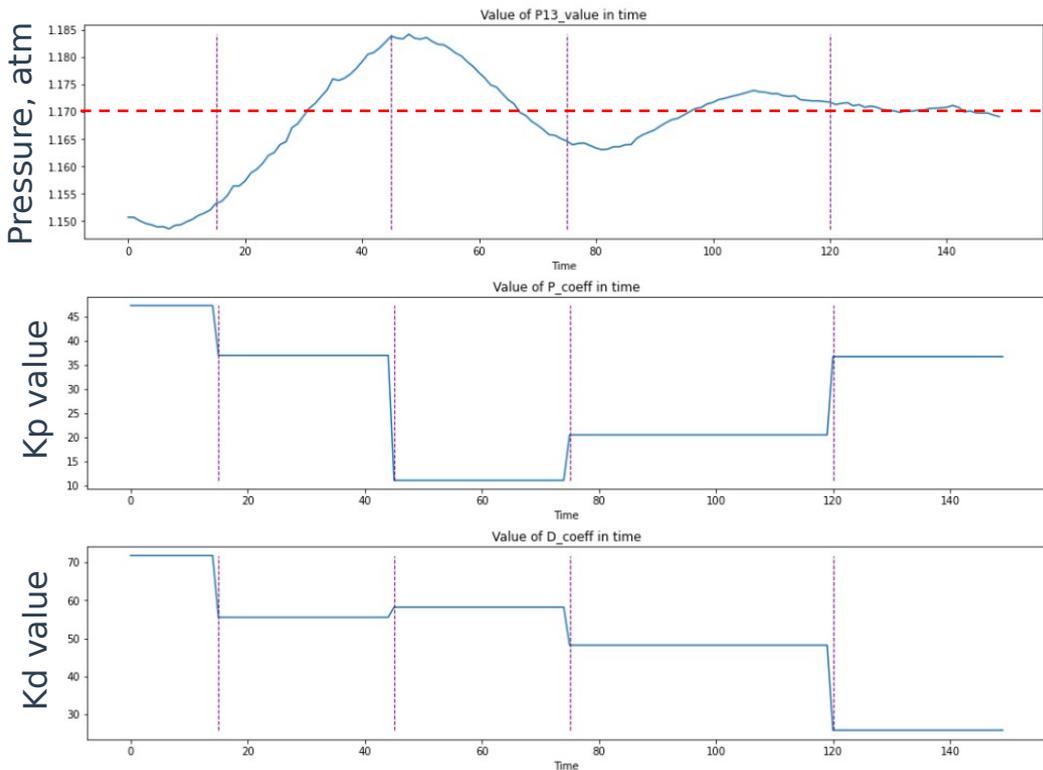
## GA parameters:

- 10 generations with 50 individuals in each
- Elitist selection
- 2 point crossover with  $P = 0.3$
- Mutation probability is 0.1



# Trajectory of coefficients

- Control interval — 4 sec

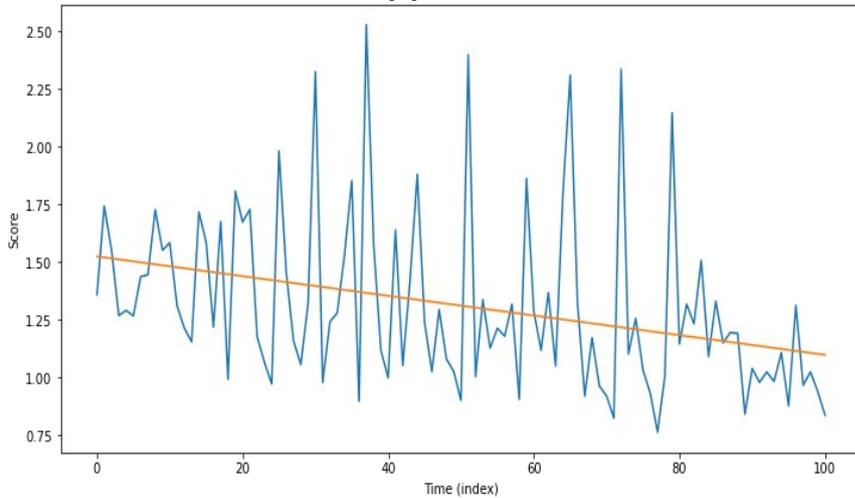


|    | A         | B         | C             | D       | E        | F       |
|----|-----------|-----------|---------------|---------|----------|---------|
| 1  | err       | err_i     | err_d         | P_coeff | I_coeff  | D_coeff |
| 2  | 0.020254  | 0.020254  | 0.020254      | 49.3988 | 37.68156 | 148.257 |
| 3  | 0.0204835 | 0.0407375 | 0.000229478   | 49.3988 | 37.68156 | 148.257 |
| 4  | 0.0211214 | 0.0618589 | 0.000637889   | 49.3988 | 37.68156 | 148.257 |
| 5  | 0.0222429 | 0.0841018 | 0.00112152    | 49.3988 | 37.68156 | 148.257 |
| 6  | 0.0229059 | 0.107008  | 0.000663042   | 49.3988 | 37.68156 | 148.257 |
| 7  | 0.0230844 | 0.130092  | 0.000178456   | 49.3988 | 37.68156 | 148.257 |
| 8  | 0.0229796 | 0.153072  | -0.000104785  | 49.3988 | 37.68156 | 148.257 |
| 9  | 0.0229883 | 0.17606   | 0.00000870228 | 49.3988 | 37.68156 | 148.257 |
| 10 | 0.0228355 | 0.198896  | -0.000152826  | 49.3988 | 37.68156 | 148.257 |
| 11 | 0.0223869 | 0.221282  | -0.000448585  | 49.3988 | 37.68156 | 148.257 |
| 12 | 0.0218146 | 0.243097  | -0.000572324  | 49.3988 | 37.68156 | 148.257 |
| 13 | 0.0212793 | 0.264376  | -0.00053525   | 49.3988 | 37.68156 | 148.257 |
| 14 | 0.0194484 | 0.283825  | -0.00183094   | 49.3988 | 37.68156 | 148.257 |
| 15 | 0.0185505 | 0.302375  | -0.000897884  | 49.3988 | 37.68156 | 148.257 |
| 16 | 0.0173177 | 0.319693  | -0.00123286   | 49.3988 | 37.68156 | 148.257 |
| 17 | 0.0219506 | 0.0219506 | 0.0219506     | 40.9325 | 35.73909 | 122     |
| 18 | 0.023212  | 0.0451626 | 0.00126135    | 40.9325 | 35.73909 | 122     |
| 19 | 0.0239828 | 0.0691453 | 0.000770807   | 40.9325 | 35.73909 | 122     |
| 20 | 0.0249614 | 0.0941067 | 0.000978589   | 40.9325 | 35.73909 | 122     |
| 21 | 0.025906  | 0.120013  | 0.000944614   | 40.9325 | 35.73909 | 122     |
| 22 | 0.026039  | 0.146052  | 0.000133038   | 40.9325 | 35.73909 | 122     |
| 23 | 0.0265942 | 0.172646  | 0.000555158   | 40.9325 | 35.73909 | 122     |
| 24 | 0.0262448 | 0.198891  | -0.000349402  | 40.9325 | 35.73909 | 122     |
| 25 | 0.0264202 | 0.225311  | 0.000175476   | 40.9325 | 35.73909 | 122     |
| 26 | 0.0257682 | 0.251079  | -0.000652075  | 40.9325 | 35.73909 | 122     |
| 27 | 0.0252886 | 0.276368  | -0.000479579  | 40.9325 | 35.73909 | 122     |
| 28 | 0.0235265 | 0.299894  | -0.00176203   | 40.9325 | 35.73909 | 122     |
| 29 | 0.0224069 | 0.222201  | -0.00102073   | 40.9325 | 35.73909 | 122     |

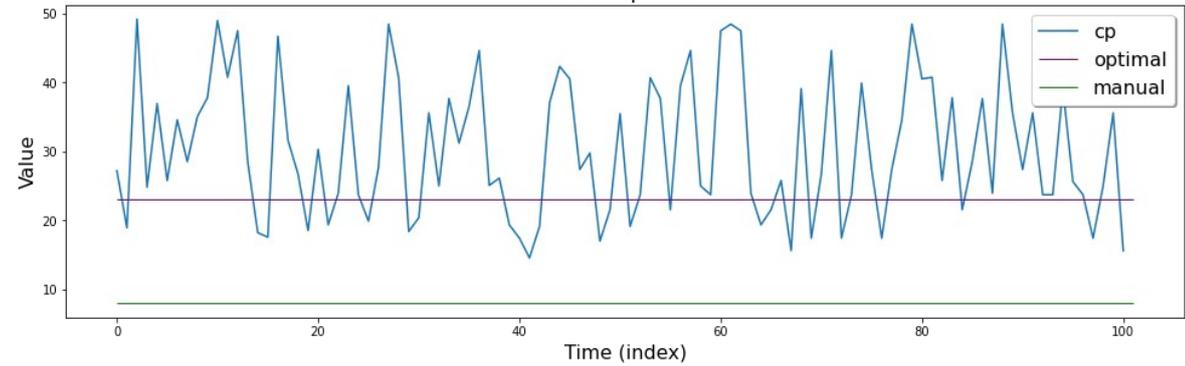
# Genetic algorithm converges



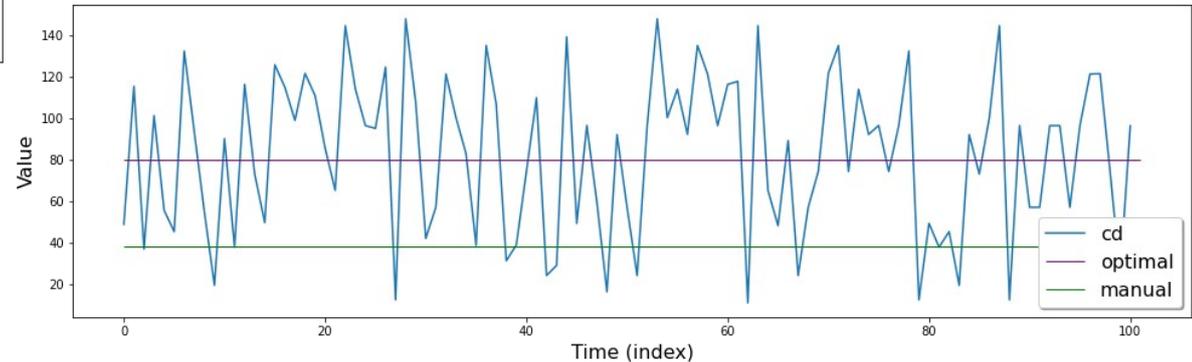
Changing of the scores in time



Value of cp in time



Value of cd in time



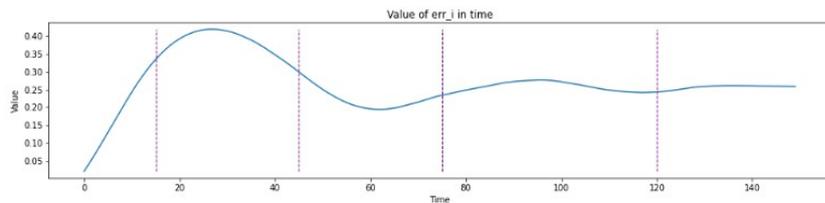
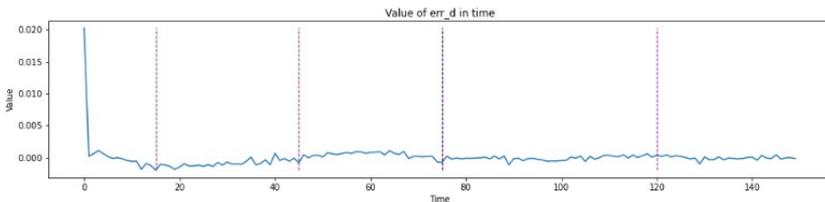
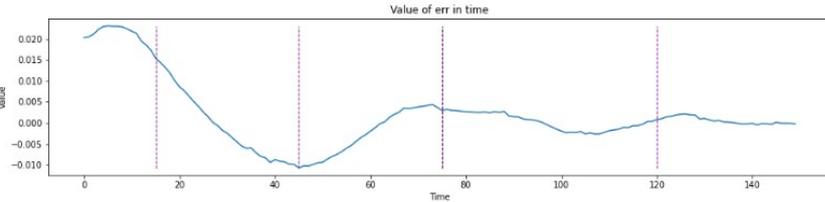
# Choosing best coefficients



- All decisions were indexed
- 3 type of scores for each decision

| <u>Score\Interval</u> | <b>0-1</b> | <b>1-3</b> | <b>3-5</b> | <b>5-8</b> | <b>8-10</b> |
|-----------------------|------------|------------|------------|------------|-------------|
| <u>Score_p</u>        | 52         | 77         | 71         | 71         | 99          |
| <u>Score_i</u>        | 52         | 77         | 79         | 4          | 15          |
| <u>Score_d</u>        | 80         | 52         | 13         | 12         | 49          |
| <u>Score_sum</u>      | 52         | 77         | 79         | 4          | 15          |

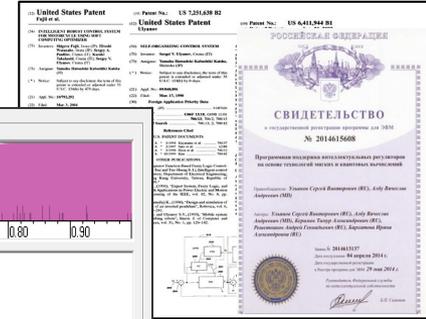
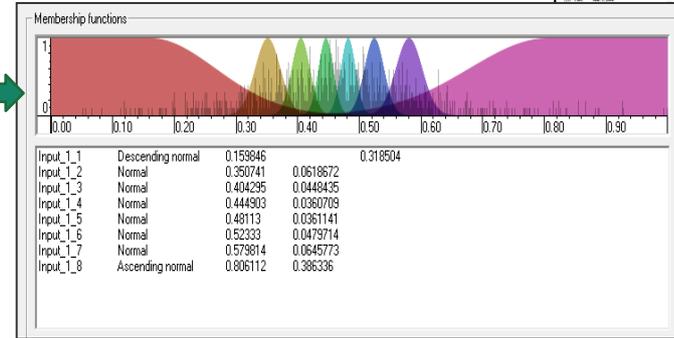
| <i>Coefficients \ Index</i> | <b>52</b> | <b>77</b> | <b>79</b> | <b>4</b> | <b>15</b> |
|-----------------------------|-----------|-----------|-----------|----------|-----------|
| $k_p$                       | 24.7054   | 32.4283   | 32.999    | 36.7192  | 14.3549   |
| $k_d$                       | 131.694   | 23.9669   | 58.5402   | 25.8489  | 25.2145   |
| $k_i$                       | 35.3736   | 31.4736   | 36.3648   | 32.9425  | 33.7652   |



# Soft Computing Optimizer KB™



\* Certificate №2011619257 of 1/12/2011 (Rus)  
 \* Patent No. US007219087B2



**Optimal structure of a fuzzy neural network**



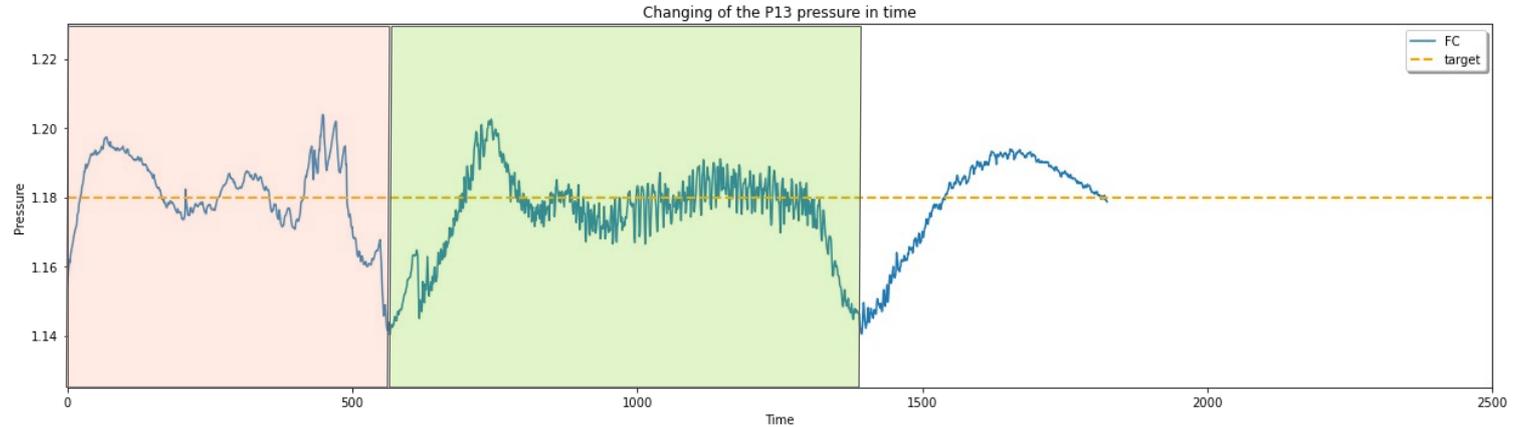
**Embedded fuzzy controller**



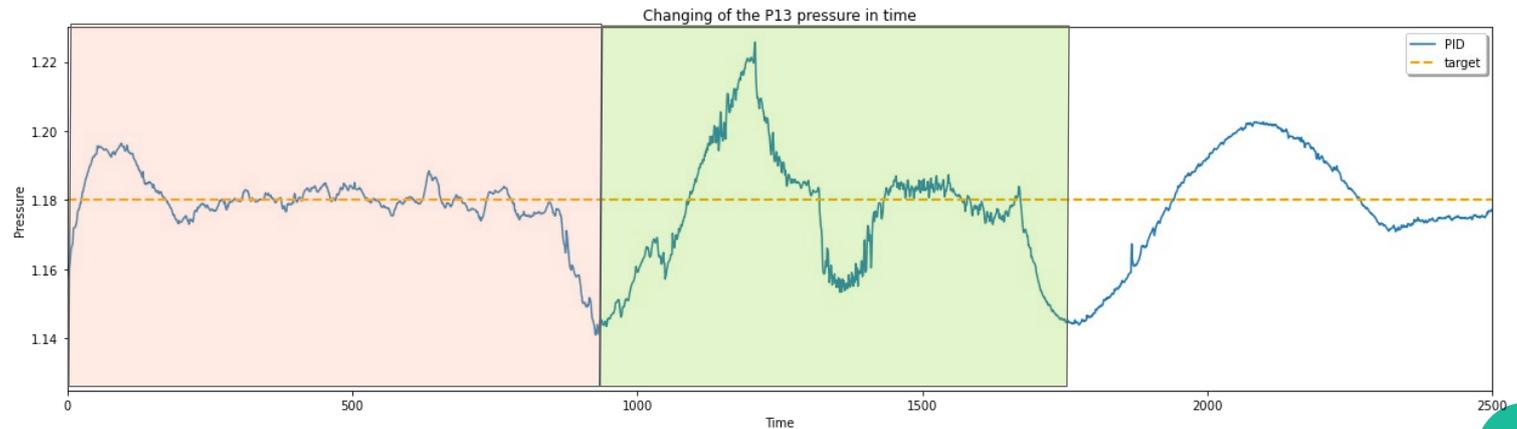
# Results of refill experiment



Fuzzy control

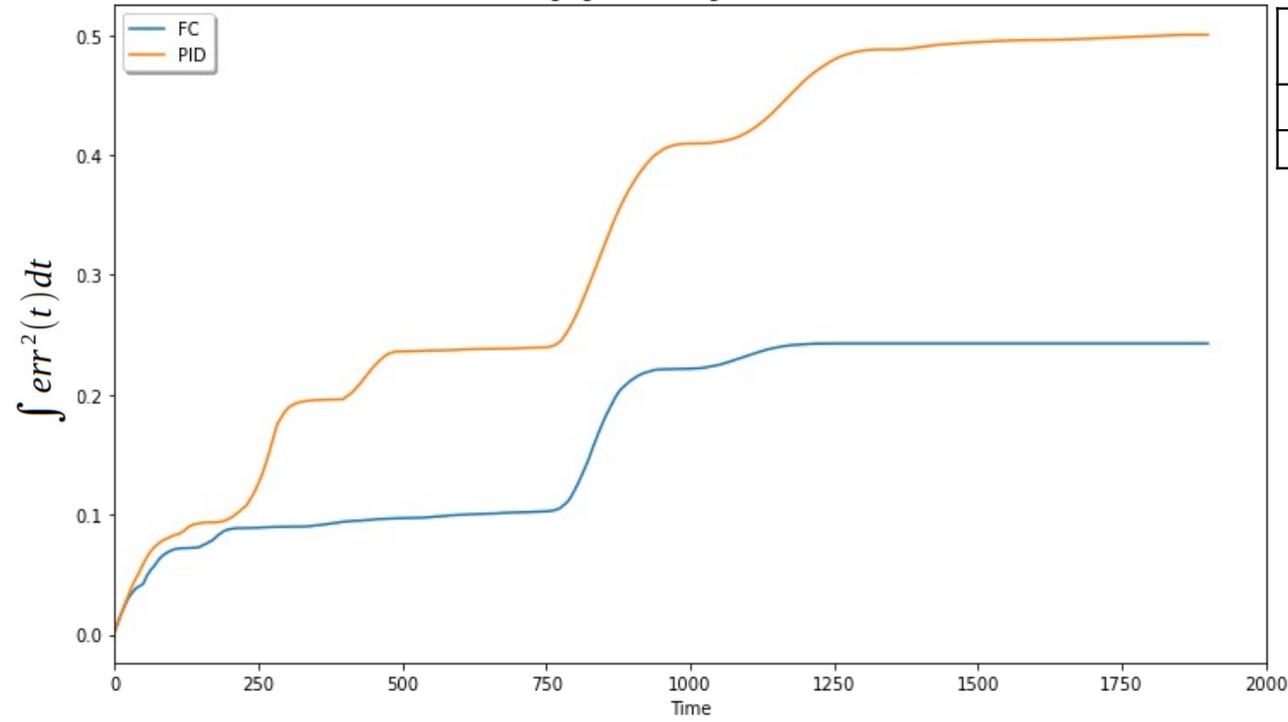


PID control

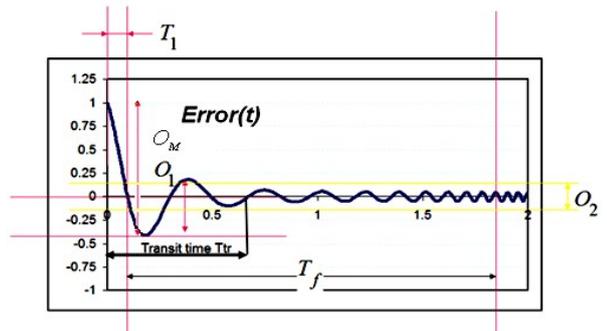


# Analysis of results

Changing of the integral error in time



|            | Performance, ticks | Over-regulation |
|------------|--------------------|-----------------|
| <b>PID</b> | 164                | 0.83            |
| <b>FC</b>  | <b>131</b>         | <b>0.59</b>     |



$$\text{Over-regulation} = \frac{O_1}{Q_M}$$

# Conclusions



- New stage of creating intellectual fuzzy controller has been added (**Fuzzy controller → Quantum fuzzy controller**)
- No need to model operator behavior
- Created software that allows to introduce the properties of adaptability and learning into the control systems of poorly formalized objects
- Technology was applied on real physical control object and it is problematically independent (first time it was applied to a task of robot-arm control)

**Thank you for attention**