Acquisition of static and dynamic parameters of biological process from experimental data

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Abstract

Methodology for static and dynamic parameter acquisition from experimental dynamic data is developed in case of homeostatic biological process with unknown functional relationships between input and output parameters.

Methodology includes assessment of static characteristic curve (including correlation analysis), transition function, reaction delay and maximal speed of output parameter change.

Methodology (except assessment of transition function) is demonstrated on example of temperature dynamics measurements of wintering bee colony as a biological object that controls microclimate in their nest. Outside air temperature was analysed as input signal and temperature above the bee nest was analysed as output parameter.

Results can be used developing a control system for biological process or object.

Keywords: *dynamic biological process, input-output relations, dynamic and static parameters.*

Introduction

Biological processes compared to the technical ones usually are not well understood in terms of cause-effect and functional relationships because biological systems are not developed by humans (Stalidzans, 2005). Sometimes the only available reliable information are experimental measurements of input (external impact on biological system) and output (output parameter of system as reaction on input) parameters of the process. Then the task is to get maximal amount of data about static and dynamic parameters of particular process from input and output curves. Processing of input-output curves is case sensitive and depends on measurement accuracy, frequency as well as process dynamics. This information can be used to predict the process or get part of necessary information for artificial control system development.

In case of homeostatic process one can assume that the target of process is known: stabilising of output parameter during fluctuations of input parameter. This assumption allows assessment of some important process parameters.

The goal of the paper is to describe methodology for static parameter acquisition from experimental dynamic data in case of homeostatic biological process with unknown functional relationships between input and output parameters. Methodology has to be demonstrated on temperature control process of bee cluster in winter.

Methodology

Methodology for process static and dynamic parameter acquisition from experimental dynamic data in case of homeostatic biological process is demonstrated on temperature control process in honeybee cluster in winter. During fluctuations of outside temperature honeybee cluster in a beehive maintain comfortable temperature (Furgala and McCutchenon, 1992).

Temperature measurements were carried out in Riga district, Latvia in November and December 2000 (Stalidzans et al., 2000). Colony size in autumn was estimated about 7-11 inhabited frames (435x300 mm each). Colonies were wintered in 15 frame single walled beehives with 120 mm high free space under frames. Bee colonies were covered with 8 cm thick cloth pillow.

DS 1820 (Dallas Semiconductor) temperature sensors were used for temperature measurements. A computer controlled measurement process. Hive temperature sensor was placed above the bee nest under the pillow in area of highest temperature (determined experimentally). Measurements of outside temperature were done with two sensors placed near to the hive in shadow on the height of pillow. Measurements are registered round the clock with time step 15 minutes.

Methodology is demonstrated on measurements of outside air temperature as an input value and parallel measurements of temperature in two hives: number 5 and 7 as output. Sequential steps of methodology are described in this chapter. Appropriate examples of methodology execution and comments are described in the chapter “Results”.

1. Parameter assessment of static characteristic

Static curve (Osis, 1969) specifies relations between input (x_{in}) and output (x_{out}) values in static position – for constant input value (x_{in} = const) appropriate output value (x_{out} = const) .

1.1. Determination of static stretch of input signal

Indications of static stretch depend on dynamic features of particular object. In ideal case x_{in} = const. Usually as static stretch is considered a stretch with relatively small fluctuations. The average value of the stretch is considered as value of a constant.

1.2. Determination of appropriate static stretch output value $x_{out\ n}$ (n = 1, 2, …, k) for static stretch value of input $x_{in\ n}$ (n = 1, 2, …, k)

Appropriate static stretch output value for static stretch value of input can be found after unknown delay. Appropriate stretch can be found determining for input value extremes appropriate output value extremes. Value of static stretch is determined by its average value.

1.3. Development of static characteristic

Values of static states build static curve: relationship between input and output values in static mode. Static curve of the process can be approximated by linear or non-linear functions.

1.4. Analysis of static characteristic

Accuracy assessed of static curve can be assessed using correlation and regression analysis.

2. Assessment of dynamic parameters of the process

If just dynamic curves of input and output parameters (x_{in} and x_{out}) and no information regarding structure and elements of biological object maximal set of possible direct or indirect parameters of process has to be gained.

2.1. Assessment of transition function

Assuming that structure of the investigated object is unknown, transition function (Osis, 1969) can not be determined directly. Principle of white and black box can be used (Wiener, 1961). White box with known structure receive the same input signal as black box. White box (its structure and parameters) has to be adapted so far that structure and parameters ensure acceptable level of difference between output signals. Then white box with known parameters can replace black box as its operational equivalent without knowing differences between structures and elements of black and white box.

2.2. Assessment of reaction delay

In case of failure determining above described appropriate white box other available parameters should be assessed even if they can not be directly used in different stability calculations of classic theory of automatic control. This kind of parameters can be used also tuning the white box as indications of some dynamic parameters.

Important parameter of dynamics is delay time of reaction on input signal. That can be assessed from extreme delay between input and output.

- Assessment of extremes of input signal

Extremes of input signal (x_{in}) are assessed approximating input data in area of particular extreme. Extreme point can be found as extreme of approximation curve.

- Assessment of extremes of output signal

Extremes of output signal (x_{out}) are assessed approximating output data in area of particular extreme that follows the extreme of input signal with some delay. After approximation extreme point can be found as extreme of approximation curve.

2.3. Assessment of highest speed of signal change

Another dynamic parameter of output signals is highest speed of its change in time unit. It can be determined as output change speed between two consequent extremes (minimum and maximum) or two consequent static stretches.

Results

Example of above-mentioned methodology is demonstrated on dynamic experimental data of temperature control in wintering bee colony.

1. Parameter assessment of static characteristic

Determination of static stretch of input signal

Static minimum stretch of input signal is determined with mean value $x_{in\ o}$=8,3 ^{o}C (Figure 1).

Determination of appropriate static stretch output value $x_{out\ n}$ (n = 1, 2, …, k) for static stretch value of input $x_{in\ n}$ (n = 1, 2, …, k).

Static minimum stretch of output signals is determined for beehives 5 and 7 with mean value respectively $x_{out\ 5}$=11,8 ^{o}C and $x_{out\ 7}$=12,5 ^{o}C (Figure 1). This kind of operations has to be repeated several times to get better results including more points for construction of static characteristic.

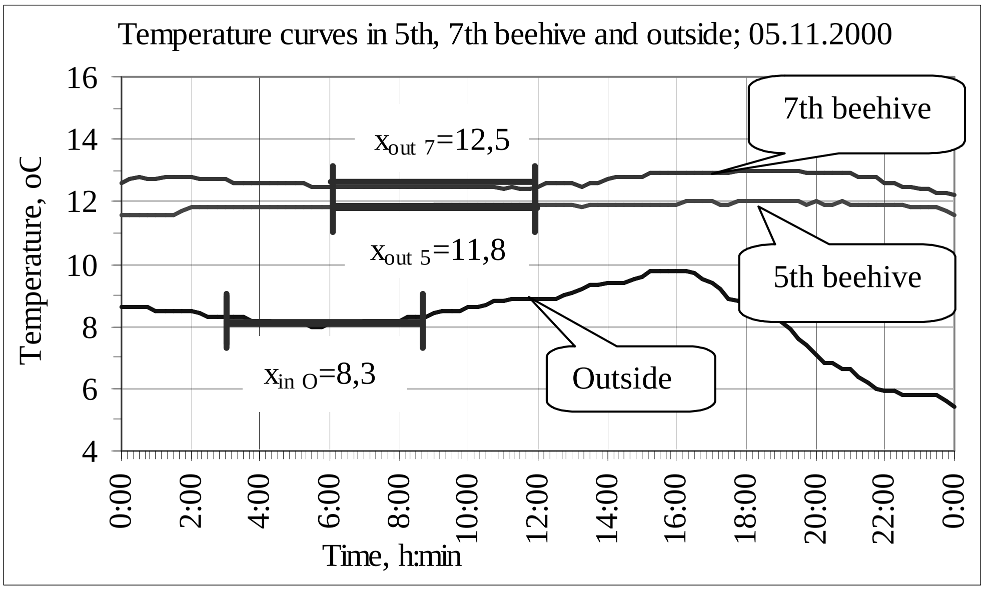

Figure 1. Determination of static stretches of input and output signals.

1.3. Development of static characteristic

Values of static stretches of input signal (outside temperature) and appropriate outputs for beehives 5 and 7 are summarised in Table 1. Values can be presented in graphic form as well (Figure 2).

1.4. Analysis of static characteristic

- Approximation of static characteristic

Analysing the figure 2 one can conclude that within the observed temperature range static characteristic is linear for both hives ($x_{out\ 5}$=0,50 x_{in}+6,6 and $x_{out\ 7}$=0,53 x_{in}+7,7). Still it can not be generalised or extrapolated for any other outside temperature range as input parameter.

Correlation coefficient between input signal (outside temperature) and output signals is for the 5-th hive $|r|_5$ = 0,92 and 7-th hive $|r|_7$ = 0,95. Thus correlation between static values of input and output in both cases are very high.

Table 1

Values of appropriate static stretches

Temp.	1., 2. Nov	3., 4 Nov	05. Nov	14. Nov	16. Nov	17. Nov	21. Nov	26. Nov	28. Nov	29. Nov
Outside	7,2	4,8	8,3	5,1	4,9	3,6	3,6	-2	-2,1	0,9
Hive 5	12,8	9,5	11,8	7,9	8,8	8,3	7,9	3,6	3,8	5,9
Hive 7	14	10	12,5	8,9	9,8	9,6	9,1	5,3	5	7,5

Temp.	01. Dec	04. Dec	06. Dec	07. Dec	08. Dec	10. Dec	16. Dec	18. Dec	19. Dec	22. Dec
Outside	6,2	4,1	3,8	3	2,9	4,9	0	-2	-2,4	0
Hive 5	8,9	9	8,6	7,9	7,2	9,2	6,9	5,9	4,9	6,6
Hive 7	10,5	10,5	10	8,9	9,1	10,3	8,1	7,3	6,9	7,9

Temp.	24. Dec	25. Dec	26. Dec	27. Dec	28. Dec
Outside	-3,2	-4,9	-5,2	-10,2	-7,1
Hive 5	5,4	5,3	4,5	2,6	3,2
Hive 7	6	6,3	5,1	2,6	4

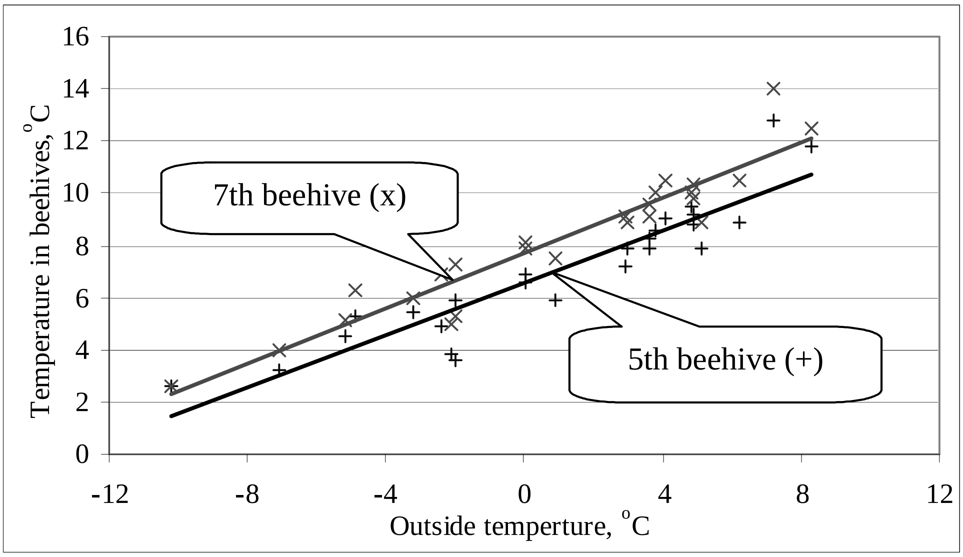

Figure 2. Values of static stretches.

2. Assessment of dynamic parameters of the process

2.1. Assessment of transition function

Transition function assessment using white and black box principle is not demonstrated in this paper.

2.2. Assessment of reaction delay

- Assessment of extremes of input signal

Assessment of extreme point is problematic because of uneven distribution of measurements. Area of input signal maximum was approximated by polynome of third order (Figure 3) that allows clearly determine coordinates of maximum point (time 12:50; temperature 11,00) independent on fluctuations during measurements.

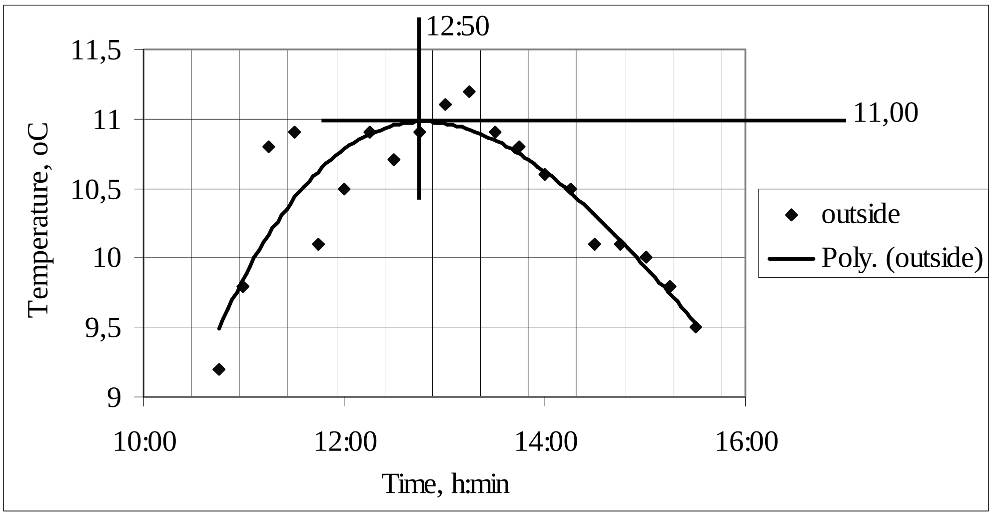

Figure 3. Determination of extreme of input signal (outside temperature).

- Assessment of extremes of output signal

Output data were approximated by polynome of third order (Figures 4 and 5).

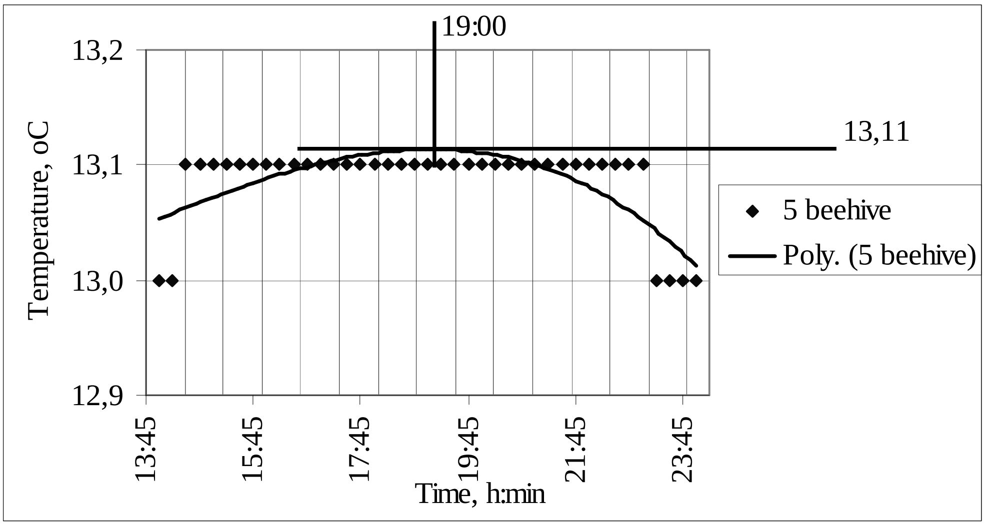

Figure 4. Assessment of output extreme for hive 5.

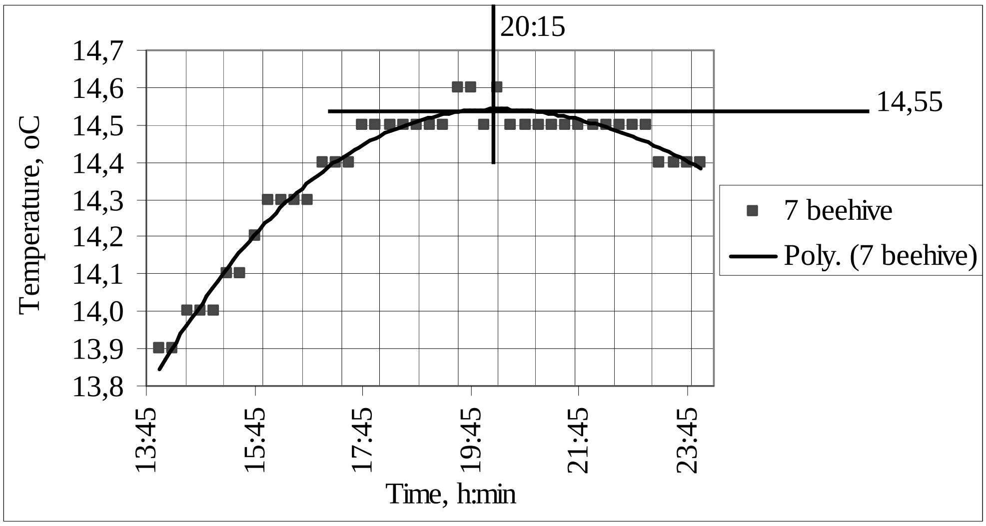

Figure 5. Assessment of output extreme for hive 7.

Extreme points are determined and summarised in the Table 2. The extreme point demonstrated in figures 3, 4 and 5 is the point No.1 in the Table 2.

Table 2

Extremes of input and output values

	1	2	3	4	5	6	7	8	9	10
Outside t°	11,0	3,8	9,4	3,2	6,9	4,5	10,2	9,7	4	6,2
5. hive t°	13,1	12	12,3	10,4	10,4	9,5	11,8	12	10,2	10,3

7. hive t°	14,6	12,7	13,6	10,7	11	10	12,7	13	10,4	10,4
Outside time	12:50	7:40	13:45	1:15	14:40	5:50	11:30	15:50	7:00	12:50
5. hive time	19:00	10:40	15:00	12:00	15:45	8:15	2:00	18:40	14:00	15:50
7. hive time	19:45	11:00	17:00	9:45	17:20	9:45	0:30	18:40	12:20	15:20

- **Analysis of acquired input and output data**

Analysing data one can conclude that output signal (x_{out}) extremes are delayed against input signals (x_{in}) with variable delay. Still comparing extreme delays for two beehives (No 5 and 7) are similar (Figure 6).

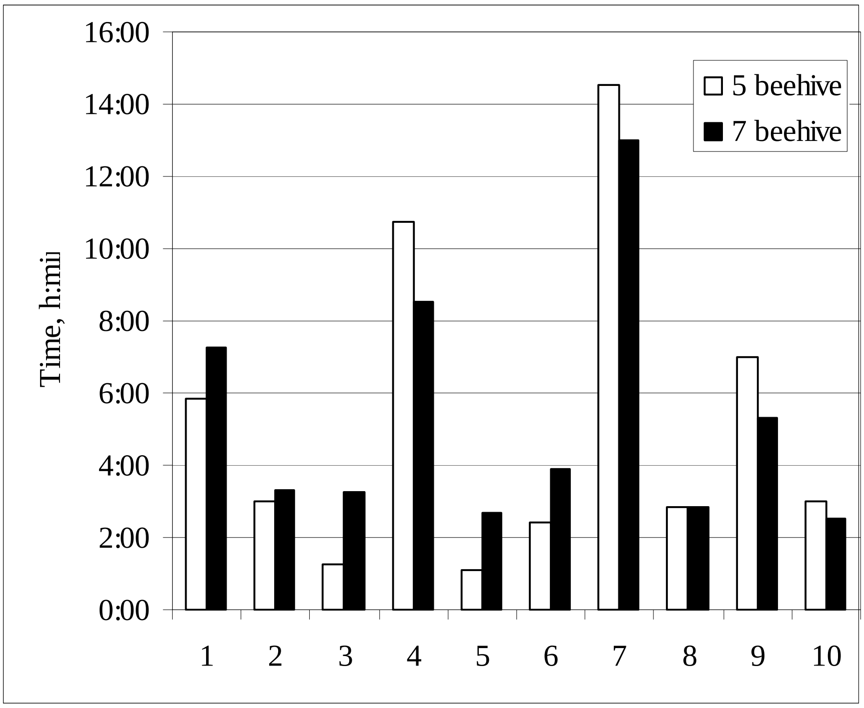

Figure 6. Reaction delay of hives 5 and 7 for 10 extreme points.

Correlation between reaction delays turns out very high |r| = 0,96. Thus in spite of wide range of delays (1 hour till 15 hours) there is high similarity in behaviour of both beehives indicating presence of unknown rule in their behaviour.

2.3. Assessment of highest speed of signal change

Highest speed of signal change is the highest value of signal change within limited time stretch. In case of available experimental data that means highest value of relation temperature change against time change with dimension [$^{o}C*h^{-1}$]. That can be measured between two sequential extremes (maximum and minimum) or two sequential static stretches (Figure 7) where extreme points are determined using 3-rd order polynomial approximation.

Speed of parameter change was determined for four points that are summarised in table 3.

Table 3

Sequential extremes of temperature changes.

	Start Time hive 5	Finish time hive 5	Time differ. hive 5	Start Temp. hive 5	Finish Temp. hive 5	Temp. differ. hive 5	Start Time hive7	Finish time hive 7	Time differ. hive 7	Start Temp. hive 7	Finish Temp. hive 7	Temp. differ. hive 7
1. extr .	10:30	15:15	4:45	12,1	12,2	0,1	10:05	16:45	6:40	12,9	13,6	0,7
2. extr.	15:15	12:00	20:45	12,3	10,4	1,9	17:00	9:45	16:45	13,6	10,7	2,9
3. extr.	8:15	2:00	17:45	9,5	11,8	2,3	9:45	0:30	14:45	10	12,7	2,7
4. extr.	18:40	14:00	19:20	12	10,2	1,8	18:40	12:20	17:40	13	10,4	2,6

- Analysis of determined output data

Highest speed of output signal change for the hive 5 is (3-rd extreme from table 3):

$$\frac{\Delta x_{out5}}{\Delta time} = \frac{2{,}3}{17{,}75} = 0{,}1296 \approx 0{,}13 \left[\frac{°C}{h}\right],$$

Highest speed of output signal change for the hive 7 is (3-rd extreme from table 3):

$$\frac{\Delta x_{out7}}{\Delta time} = \frac{2{,}7}{14{,}75} = 0{,}1831 \approx 0{,}18 \left[\frac{°C}{h}\right].$$

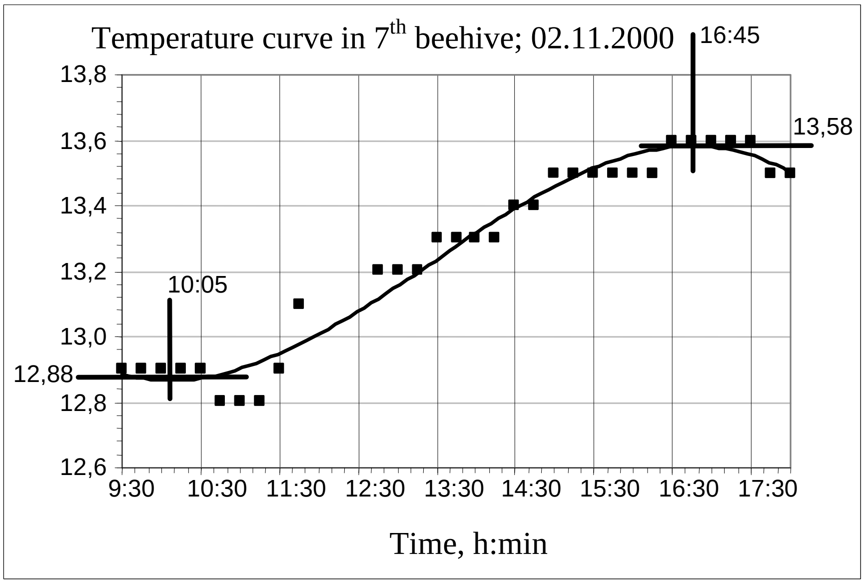

Figure 7. Determination of sequential extreme points for hive 7.

Analysing determined and calculated data one can conclude that the colony in 5-th hive is more inert than the on in 7-th hive. Still the maximal speeds of output signal change for both hives is similar and give some general indication about their dynamic parameters.

It is possible to get more valuable parameters if experiments with a ramp type of input signal change like it is often done with technical systems.

Described methodology tends to extract maximal information from limited amount of experimental input-output data of biological system under natural conditions. Other methods can be used if dedicated experiments are possible to assess dynamic parameters.

Conclusions

Methodology for static and dynamic parameter acquisition from experimental dynamic data is developed for homeostatic biological process with unknown functional relationships between input and output parameters.

Methodology consists of two parts: static characteristic assessment (static characteristic curve including correlation analysis) and dynamic characteristic assessment (transition function, reaction delay and maximal speed of output parameter change).

Methodology (except assessment of transition function) is demonstrated on example of temperature dynamics measurements of wintering bee colony as a biological object that controls microclimate in their nest. Outside air temperature was analysed as input signal (x_{in}) and temperature above the bee nest was analysed as output parameter. As output parameters two hives (No. 5 and 7) were analysed with output signals $x_{out\ 5}$ and $x_{out\ 7}$. Static characteristic for both colonies in hives determined as $x_{out\ 5}$=0,50 x_{in}+6,6 and $x_{out\ 7}$=0,53 x_{in}+7,7. Reaction delays were in wide range from 1 to 15 hours still having very high correlation between beehives: |r| = 0,96. Highest speed of output parameter change for the hives 5 and 7 was determined accordingly 0,13 [$^oC*h^{-1}$] and 0,18 [$^oC*h^{-1}$].

Methodology can be used developing a control system for biological process or object under conditions of insufficient information.

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