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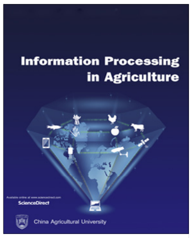

Dynamic simulation based method for the reduction of complexity in design and control of Recirculating Aquaculture Systems

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A B S T R A C T

In this work we introduce the “Extensible Fish-tank Volume Model” that can reduce the complexity in the design and control of the Recirculating Aquaculture Systems. In the developed model we adjust the volume of a single fish-tank to the prescribed values of stocking density, by controlling the necessary volume in each time step. Having developed an advantageous feeding, water exchange and oxygen supply strategy, as well as considering a compromise scheduling for the fingerling input and product fish output, we divide the volume vs. time function into equidistant parts and calculate the average volumes for these parts. Comparing these average values with the volumes of available tanks, we can plan the appropriate grades. The elaborated method is a good example for a case, where computational modeling is used to simulate a “fictitious process model” that cannot be feasibly realized in the practice, but can simplify and accelerate the design and planning of real world processes by reducing the complexity.

1. Introduction

Global need for the quantitatively and qualitatively secure fish products requires the fast development of Recirculating Aquaculture Systems (RAS). These complex production systems have an increasing role, providing healthy food for the growing population [1]. In addition to its health promoting and poverty reducing capacity, aquaculture sector has a significant role in creating jobs and livelihood for hundreds of millions of the population, worldwide.

According to the up-to-date statistics in the report on The State of World Fisheries and Aquaculture [2], Asia produces more than 88% of the total aquaculture production in the world, while almost 70% of this Asian production comes from China. Europe, with its 4.3%, obviously needs to enhance its performance in this sector. European Aquaculture Technology and Innovation Platform were founded to cover the diverse range of challenges in the field, and set out a strategic agenda [3]. However, effective and promising execution implies the involvement of Asian, especially Chinese collaboration to the work program. On the other hand, the fast development of Eastern countries has to be accompanied by the highest standards of environmental protection.

Main driver of research in this field is that the population’s increasing demand for fish and seafood products exploited the natural resources of oceans. Considering the increasing need for sustainable intensification of aquaculture systems, recycling aquaculture systems (RAS) came to the front in

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the past decades. These systems, supplemented by advanced tools and methodologies, as well as running under controlled conditions, with almost closed water recycling loops, are designed to provide the appropriate amount and high quality fish- and seafood products, with the possible minimal load on environment. Several papers focus on the design and optimal performance of these systems (e.g. [4]). Recent technological advancements make possible the deployment of modern methods for detection and control of aquaculture systems in various aspects (e.g. [5,6]).

Aquaculture sector competes highly on the natural resources (water, land, energy, etc.) with the other resource users. Considering this, the development of the sustainable and profitable aquaculture systems must work with considerably decreased fresh water supply, that needs the application of sophisticated design, decision supporting and control tools. Accordingly, dynamic modeling and simulation supported design and operation of RAS are in the focus of research and development.

RASs are artificially controlled isolated systems that need maximal recycling of purified water with minimal decontaminated emissions. Also, these isolated systems need disinfected water supply from the environment. Accordingly these process systems integrate animal breeding with complex bioengineering and other process units in a feedback loop. In addition the fish production has to be solved in a stepwise, multistage process, which is also coupled with the characteristics of the life processes (e.g. with the differentiation in growth).

The main challenge in this field is to increase its capacity and to ensure its sustainability in the environment, at the same time. In addition it is highly affected by the long term climate change, as well as by the more frequent extreme weather situations. This can be managed only by the utilization of advanced information technologies for design, planning and control of aquaculture systems.

Advanced Information Technology has been developing more and more powerful hardware and software tools for global communication to share the accumulated data and knowledge, as well as for optimal design and control of complex systems. Formerly these results were utilized mainly by the industrial and service sectors. However, in the forthcoming period life sciences and applied life sciences (including agriculture, aquaculture, food, forestry, freshwater and waste management, as well as low carbon energy sectors) must have a pioneering role in going ahead, assisted by the newest results of Advanced Information Technology.

One of the challenging possibilities of computational modeling is that we can simulate also “fictitious processes” that cannot be feasibly realized in the practice, however the use of these models can simplify and accelerate the design and planning of real world processes by reducing the complexity in the early phase of problem solving.

It is worth mentioning that the rapidly evolving biosystems based engineering technologies have the advantage of last arrival in the application of up-to-date results of Information Technology. It means that the implementation of new methodologies can be cheaper and more effective if it starts in a “green field". Moreover the new technologies can be developed in parallel with the development of IT methods and tools.

The obvious gap between the (applied) life sciences and informational technologies has to be bridged by new modeling methodologies of process engineering, which evolve fast, motivated also by the above situation.

Computational modeling and simulation can definitely contribute to the effectiveness of aquaculture systems. Especially, complex RAS requires the simulation model based design and operation; consequently it became an active research field in the past years (e.g. [7,8]). There is a fast development also in model based understanding and control of net cage aquaculture processes (e.g. [9]).

The applied modeling methodologies vary in a broad range, from EXCEL spreadsheet calculations [10] to the sophisticated fish growth and evacuation model, combined with a detailed Waste Water Treatment (WWT) model in an integrated dynamic simulation model [8].

In the intensive tanks of the recycling systems the various nutrients, supplied with feed, are converted into valuable product. Considering the sound material balance of the system, many papers focus on the nutrient conversion and on material discharge [11,12]. Supply chain planning and management of aquaculture products is also a challenging question in the field [13,14]. Several research papers deal with the two-way interaction of aquaculture with environment, in general [15–17]; or focusing on actual fields of this interaction [18,19]. Up-to-date research works call the attention also to the importance of knowledge transfer and exchange of experience between field experts and policy makers. Also the importance of well established and conscious regulations (e.g. [20,21]) is emphasized.

The complexity in design and control of RAS comes from the fact that the prescribed stocking density needs a fast increasing volume of the subsequent stages, while the concentrations, determining growth of fishes, as well as waste production depend on the volume of the fish-tanks. As a consequence, the optimal feeding, grading, water exchange and oxygen supply strategies cannot be determined by modeling of a single tank, rather it must be tested for the various possible system structures. There are many variants in planning and scheduling decisions, based on the available number of tank volumes. In addition there is an additional combinatorial complexity in design, where the volumes of the tanks for the subsequent grades are also to be optimized. In this paper we show, how a fictitious “Extensible Fish-tank Volume Model” can help to reduce the complexity in the design and control of the Recirculating Aquaculture Systems.

2. Objective and approach

In our previous work, we implemented and tested an example RAS model by the Direct Computer Mapping based modeling and simulation methodology [22]. Based on these previous results we tried to develop a model based complexity reducing method for the design and control of RAS. Complexity comes from the fact that the prescribed stocking density in RAS needs an increasing volume in the subsequent stages, while all of the concentrations, determining growth and waste production of the fishes depend on the volume of the tanks. Accordingly the number of possible feeding, water exchange and oxygen supply strategies must be multiplied with number of possible system structures, resulting an enormous complexity. Computational modeling makes possible to simulate also those “fictitious processes” that cannot realized in practice, but their use can reduce the complexity of design and control. In this paper we show, how a so-called fictitious “Extensible Fish-tank Volume Model” makes possible the preliminary design and planning of the Recirculating Aquaculture Systems with the simulation of a single “fictitious” fish-tank.

3. Method and data

3.1. *Applied method: Direct Computer Mapping of process models*

The complex, hybrid and multiscale models claim for clear and sophisticated coupling of structure with functionalities. Multiscale, hybrid processes in biosystems and in human-built process networks contain more complex elements and structures, than the theoretically established, single mathematical constructs. Moreover, the execution of the hybrid multiscale models is a difficult question, because the usual integrators do not tolerate the discrete events, while the usual representation of the continuous processes cannot be embedded into the discrete models, conveniently.

There are available methods for modeling continuous changes combined with discrete events, like Hybrid Petri Nets (e.g. [23]), but the functionality (and adaptability) of their state and transition elements is limited by the underlying sophisticated mathematical definitions, that give the sound basis of these constructs. On the other side, there are freely programmable agent based solutions (e.g. [24]), while there is not a well defined structure of these optional agents. To overlap this gap, in the multidisciplinary and multiscale applications the various sub-models are often prepared with quite different methods, while their common use is supported for example by the model integration interfaces (e.g. [25]).

In Direct Computer Mapping (DCM) of process models ([26,27]) we apply another intermediate solution, where the generic state and transition prototypes support the free declaration of the locally executable programs for the well structured network elements. Accordingly, the natural building blocks of the elementary states, actions and connections are mapped onto the elements of an executable code, directly. The principle of DCM is that “let computer know about the very structures, very building elements and feasible bounds of the real world problem to be modeled, directly”. DCM restricts the simulation model to remain inside the feasible domain, as well as uses a common representation for “model specific conservation law based” and “informational” processes. This makes possible the application of the methodology for a broad range of processes from the low-scale cellular biosystems [28] through process systems (pyrolysis) [29] up to the large-scale agrifood [30] and environmental process networks [31].

In DCM all of the models can be built from two unified meta-prototypes of the state and transition elements as well as from five types of connections (Fig. 1) that can be executed by a general kernel. The state and transition elements differ from each other according to the structural point of view of State / Transition Nets. In DCM the state elements represent the quantitative extensive (additive) and intensive properties and/or the qualitative signs (in form of optionally structured symbolic or numerical data). The state element, starting from the initial conditions, with the knowledge of the summarized (integrated) changes and/or collected signs, coming from the various transitions, determine the output intensive parameters, as well as the output signs. The transition elements calculate the expressions determining the coordinated changes of extensive properties and execute the prescribed rules with the knowledge of the input data and parameters, while their output changes and signs are forwarded to the states' input, according to the inherent feedback characteristics of process systems. The state elements characterize the actual state of the process (ellipse), while the transition elements describe the transportations, transformations and rules about the time-driven or event-driven changes of the actual state (rectangle). The increasing (solid) and decreasing (dashed) connections transport additive measures from transition to state elements. The signaling connections (dotted), carrying signs from state to transition elements and *vice versa*.

The state and transition elements contain lists of parameter (Sp or Tp), input (Si or Ti) and output (So or To) slots (circles and rectangles). The local functionalities of the state and transition elements are described by the local program code, while usually many elements use the same program, declared by the prototype for the given subset of elements. The connections carry data triplets of d(Identifier,Valuelist,Dimen sions) from a sending slot to a receiving slot.

The cyclically repeated steps of the execution by the general purpose kernel are as follows:

(1) The modification of state inputs by the transition/state connections.
(2) The execution of the local programs, associated with the state elements.
(3) The reading of state outputs by the state/transition connections.
(4) The modification of transition inputs by the state/transition connections.
(5) The execution of the local programs, associated with the transition elements.
(6) The reading of transition outputs by the transition/state connections; and cyclically repeated from (1).

3.2. *Applied data set: empirical relationships for African catfish from the literature*

We utilized the available empirical data and equations for African catfish [32]. The example system starts with the stocking of fingerlings with an average of 10 g/piece and ends with an average of 900 g/piece product fish after a 150 days long breeding period, divided into 5 equidistant parts

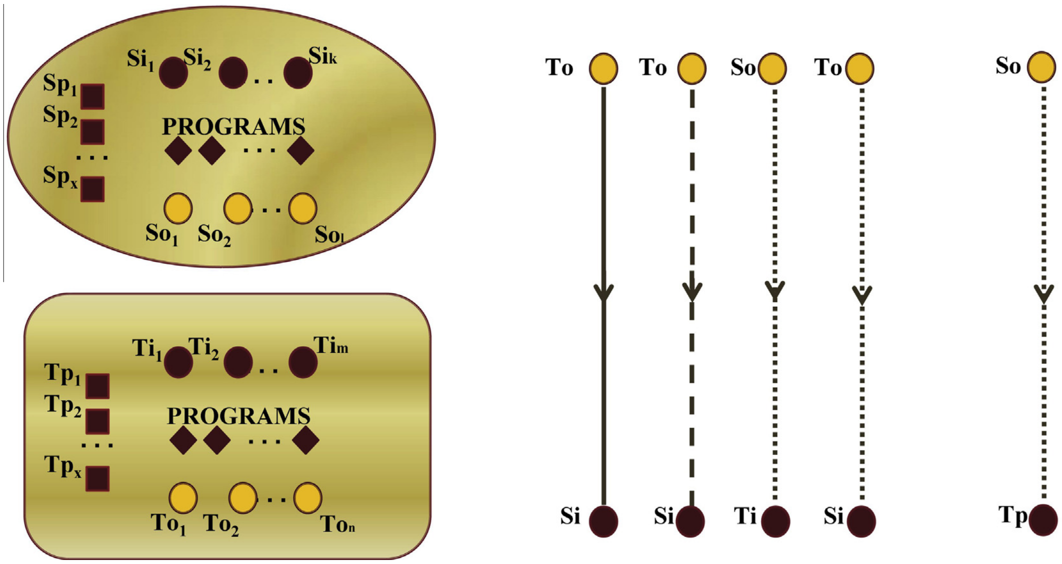

Fig. 1 – Metaprototypes of elements and connections.

resulting a 30 days harvesting cycle. The empirical equations for the calculation of the body weight of the given species are the followings:

$$BW = 0.031 * X^2 + 1.2852 * X + 9.4286 \tag{1}$$

$$\text{Mortality}, \% = 57.86 * BW^{-0.612} \tag{2}$$

$$\text{Consumed feed in } \% \text{ of } BW = 17.405 * BW^{-0.4} \tag{3}$$

$$\text{Feed conversion rate}, g/g = 0.441 * BW^{0.117} \tag{4}$$

$$\text{Dry matter in } \% \text{ of } BW = 17.267 * BW^{0.0778} \tag{5}$$

$$\text{Protein content of fish in } \%\text{of } BW = 14.372 * BW^{0.0234} \tag{6}$$

where, BW = the body weight, g; X is the age of fish, day.

Calculation of metabolic waste emission requires the approximate nutrient composition. According to the example diet composition, we calculated with the following concentrations of components: 490 g/kg protein, 120 g/kg fat, 233 g/kg carbohydrate, 77 g/kg ash, altogether 920 g/kg dry matter.

Organic matter content can be quantified as Chemical Oxygen Demand (COD). In the referred example system authors give empirical numbers for converting food components into COD as follows: protein: 1.25 g COD/g nutrient, fat: 2.9 g COD/g nutrient, carbohydrate: 1.07 g COD/g nutrient.

3.3. *DCM based implementation of the RAS model*

The simplified general scheme of the Recirculating Aquaculture System is shown in Fig. 2. In some system a Sludge1 is filtered before the wastewater treatment WWT. If the sludge is utilized in agriculture, then instead of Sludge1 a Sludge2 is removed after nitrification and Biological Oxygen Demand (BOD) removal and in case of nitrate sensitive fishes nitrate is removed in a following denitrification step. The fresh water supply can be supplied by the recycling purified water. The inlet (recycle + fresh) water has to be saturated with oxygen.

The structure of the fish-tank system, used to ensure the prescribed stocking density along the weight increase of fishes is illustrated in Fig. 3. The fishes are moved forward stepwise, starting with the final product from the last stage and ending with the supply of the new generation of fingerlings.

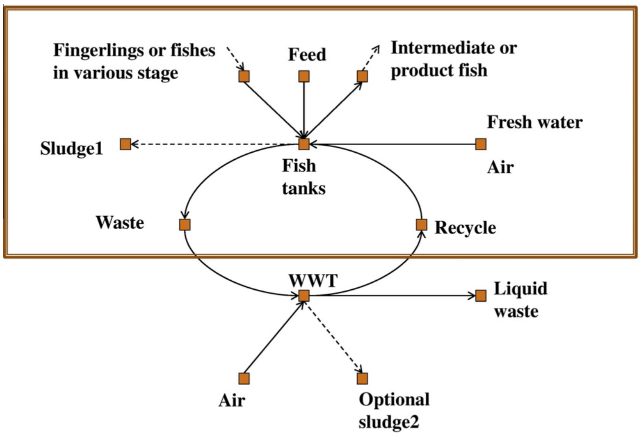

Fig. 2 – General flow sheet of the RAS.

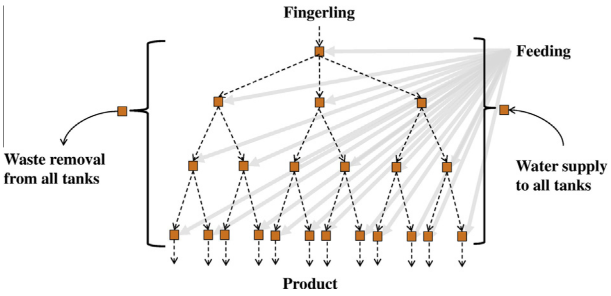

Fig. 3 – System of multiple fish-tanks for grading.

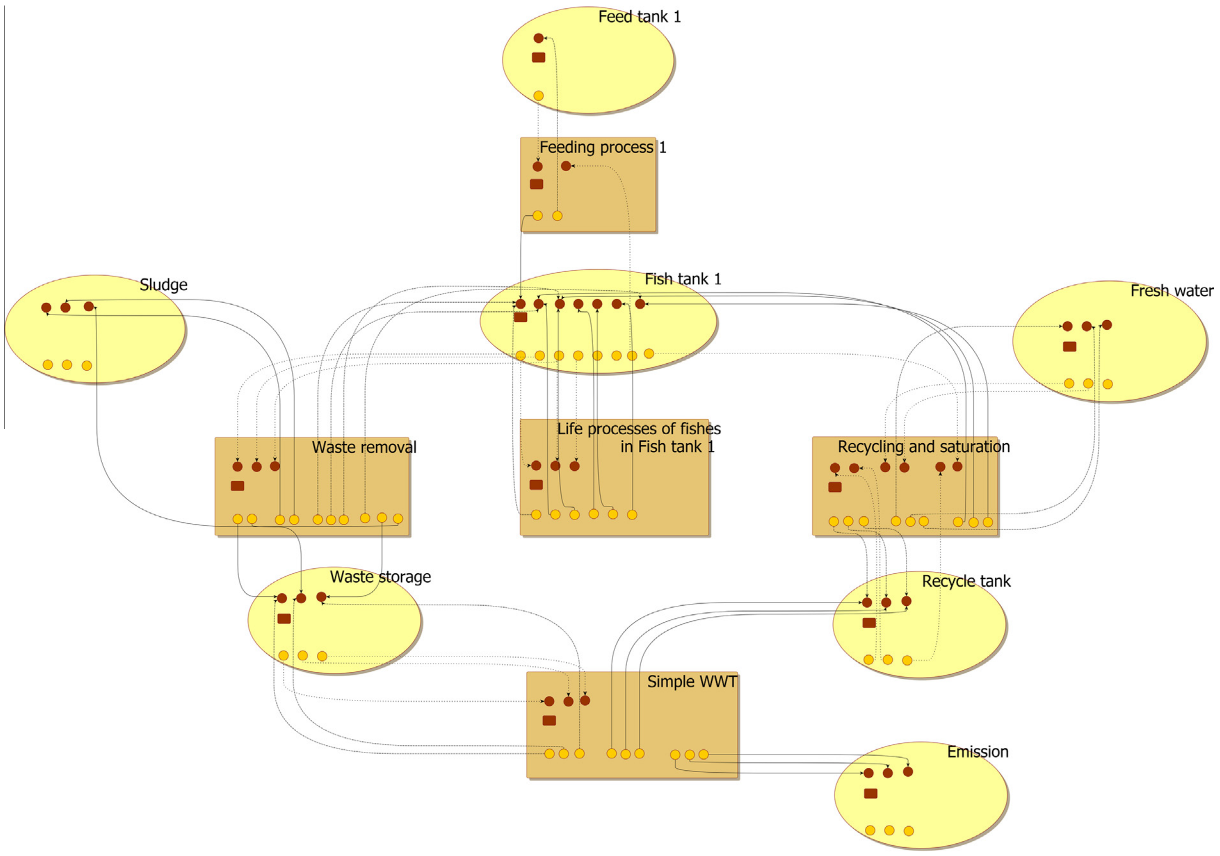

Fig. 4 – DCM implementation of the RAS model.

The DCM model of the RAS scheme (according to Fig. 1), built from the unified meta-prototypes, shown in Fig. 1 can be seen in Fig. 4.

In a realistic model of the RAS system the state elements, representing the fish-tanks and the associated transition elements, representing the respective life processes (growth, excretion, mortality, etc.) can be multiplied by copying these elements and, by multiplying the necessary connections, according to the scheme of Fig. 3.

The DCM model can be transformed into the state space model of the control. It means that we can extend or modify the program of the prototype elements to calculate the (input) control actions from the measured (output) characteristics. (In differential equation representation this corresponds to the transformation of the balance equations into another form describing the so called "state transition" and "output" functions [33] from control engineering point of view.) It is to be noted that in the DCM based control model new kind of connections that modify the parameters, determining the control actions have to be added.

Fig. 5 shows an example for the fish-tank related part of RAS (designated by a rectangle in Fig. 2). The control connections (signed with red lines) illustrate the following simplified, simulated measurement (Y) → control action (U) system of RAS:

Ammonia concentration (Y1, g/m^3) is controlled by the inlet water flow rate (U1, m^3/h):if Y1 > Y1set then U1 = Vol^{*}(Y1-Y1set)/($Y1set^{*}$DT)

Tank level (Y2, m) is controlled by the outlet flow rate (U2, m^3/h):if Y2 > Y2set then U2 = A^{*} (Y2-Y2set)/DT

Mass of fishes (Y3, kg/m^3) is controlled by feeding rate (U3, kg/h):if (Y3 < Y3set and F < Flimit) then U3 = Vol^{*}(Flimit - F)/DT

Oxygen concentration (Y4, g/m^3) is controlled by the oxygen supply (U4, g/h):if Y4 < Y4set then U4 = Vol^{*}(Y4set - Y4)/DT

where A is the cross sectional area of the tank, m^2; DT = the time step, h; Vol = the volume of the tank, m^3; F = the amount of unconsumed feed in the tank, kg/m^3; Flimit = the prescribed amount of unconsumed feed in the tank, kg/m^3; and "set" refers to the set point of the respective variable.

4. The developed complexity reduction method

Computational modeling makes possible to simulate also those "fictitious processes" that would have been realized in principle, but their practical realization is not feasible, however their calculation helps to reduce the complexity of problem solving. In this paper we show, how a fictitious "Extensible Fish-tank Volume Model" can help to reduce the complexity in the design and control of the RAS. In the developed Extensible Fish-tank Volume Model we adjust the volume of a single fish-tank to the prescribed values of stocking density, by controlling the necessary volume in each

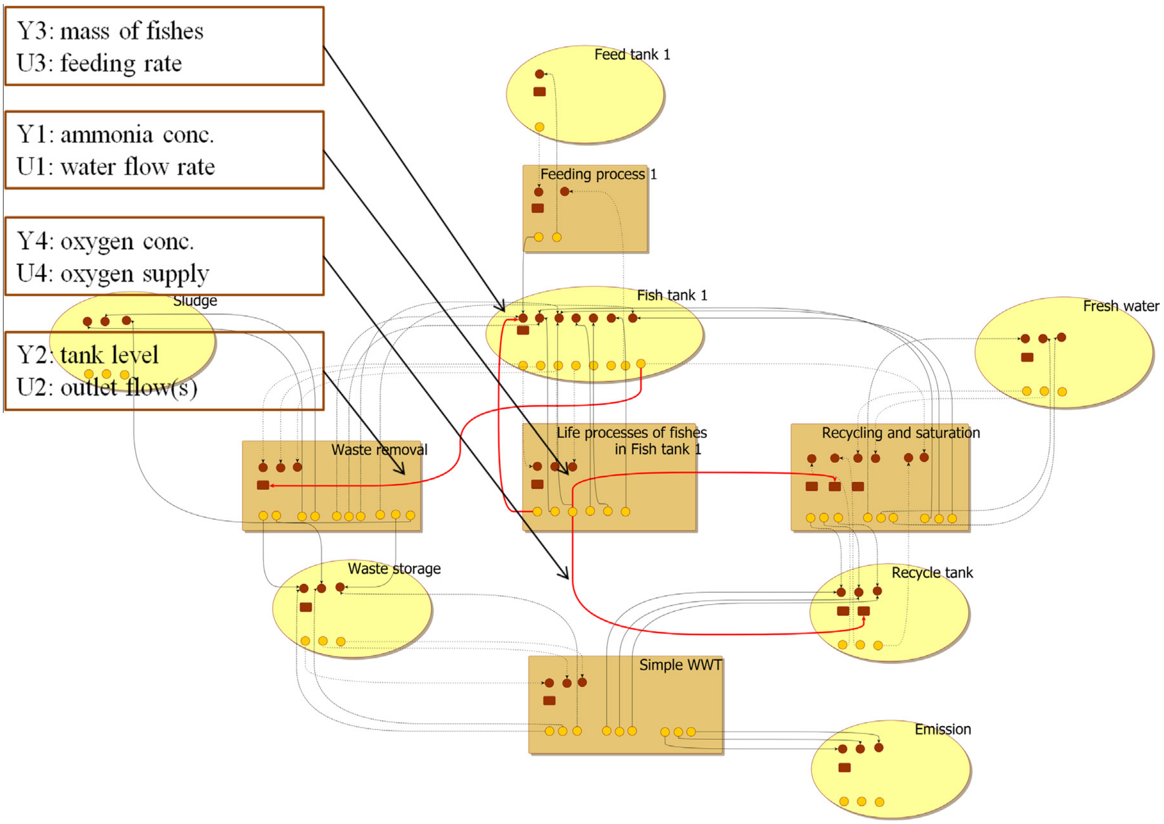

Fig. 5 – Implementing control elements in the DCM based state space model of RAS (Y's are for measurable output variables, U's are for the controllable input variables).

time step. Having developed an advantageous feeding, water exchange and oxygen supply strategy, as well as considering a compromise scheduling for the fingerling input and product fish output, we divide the volume vs. time function into equidistant parts and calculate the average volumes for these parts. Comparing this average values with the volumes of available tanks we can plan the appropriate stages. Finally, having simulated the respective structure we can optionally refine the solution, iteratively.

4.1. *Complexity of the RAS design and control*

The complexity in the design and control of RAS can be evaluated from the overview of the parameters, determining the degree of freedom, as follows:

Parameters of fish-tank model

- Individual fish model
  - Feed consumption (as a function of mass)
  - Growth function
    - utilization of feed component (as a function of mass)
    - excretion of fecal (as a function of mass)
    - oxygen consumption and carbon-dioxide emission (as a function of mass)
    - excretion of ammonia and/or urea (as a function of mass)
- Fish population model
  - Stocking density
    - initial for fingerlings
    - for mature fishes (as a function of mass)
- Mortality (as a function of mass)
- Differentiation in growth
    - in feed consumption
    - in feed utilization
- Individual fish-tank model
  - Feeding
    - quantitative
    - qualitative
    - scheduling
  - Water exchange
    - exchange rate
    - dissolved component limitation and balance
    - solid component limitation and balance
  - Optional oxygen supply our ventilation (with oxygen and carbon-dioxide transport)

Parameters of tank system model

- Fish production
  - quantity
  - quality (protein, fat and water content)
  - scheduling

Fish-tank system model
- number of stages
- available (or designed) tank volumes
- volume (number) of tanks in the subsequent stages

Parameters of WWT model

Load
- Water demand
- Ratio of fresh water supply

Structure of waste water system (as a consequence of limitations, only in design phase)
- Solid removal + biofilter
- Solid removal + nitrification + BOD removal + denitrification
- Nitrification + BOD removal + Solid removal + denitrification

Prescribed limitations for recycling water
- Components (ammonia, nitrite, nitrate, etc.)
- BOD
- Solid content

Prescribed limitations for waste water emission
Prescribed limitations for sludge emission
Water supply
- Saturation with oxygen
- Disinfection of fresh water supply

The most difficult problem is that the prescribed stocking density needs a highly increasing volume of the subsequent stages, as well as all of the concentrations, determining growth and waste production of the fishes depends on the volume of the tanks. Accordingly the optimal feeding, grading, water exchange and oxygen supply strategy cannot be solved by modeling of a single tank, rather it must be tested for the various possible system structures. Accordingly the number of possible feeding, scheduling, water exchange and oxygen supply strategies must be multiplied with number of possible system structures and of the respective grading. There are many structural variants of the systems, also in the case of scheduling and control decisions for the available number of volumes of tanks (comprising usually 2–3 kinds of different volumes). There is additional combinatorial complexity of design, where the volume of the tanks is also to be optimized.

The complexity, coming from the WWT in the control of an existing system can be treated more easily, because the capacity of the WWT, as well as the prescribed emitting and recycling concentration values almost determine the volume (and accordingly the ratio) of the recyclable water. Resulting from this reasoning, for the preliminary calculations the WWT system can be taken into consideration with efficiency factors. However the degree of freedom of WWT design is very high, especially if we must select from the quite different technological structures. This, combined with the complexity issues of the fish, fish-tank and tank system models makes a difficult problem to be solved.

4.2. *Complexity reduction by applying the Extensible Fish-tank Volume Model*

Motivated by the above discussed needs for complexity reduction, we tried to solve the approximate optimization of feeding, scheduling, water exchange and oxygen supply strategies separately from the possible system structures. As a possible solution we can utilize the following features of the simulation model:

(i) we can extend the simulation model with so-called “model controllers” that change some model parameters according to some prescribed properties; and
(ii) we can simulate also hardly realizable, but feasible “fictitious models".

Actually, we use a model controller that makes possible the previous optimization of feeding, water exchange and oxygen supply strategies, without trying this for the possible system structures, but in a single fish-tank model. In the fictitious Extensible Fish-tank Volume Model we adjust the volume of a single fish-tank to the prescribed value or function of stocking density, by controlling the necessary volume in each time step of the simulation.

Actually in this fictitious simulation tests we do calculations of the RAS system with a single fish tank, that changes its volume according to the prescribed stocking density function (or value). We start the simulation with the prescribed stocking density of fingerlings, and in each time step of the simulation check the difference of the continuously increasing stocking density from the prescribed (constant or optionally changing) value. If the stocking density higher than the set point, then we calculate the surplus amount of the input water that dilutes the fish tank to achieve the set point of the stocking density. Simultaneously we increase the set point of the level for the calculation of the water output. With this surplus water inlet we can achieve the prescribed stocking density along the whole production from the fingerlings to the final product in a single (fictitious) fish tank. This make possible to decrease the complexity of the previous optimization, and also we can simulate and study the effect of the various stocking densities on the RAS process.

Having developed an advantageous feeding, water exchange and oxygen supply strategy, and considering a compromise scheduling for the fingerling input and product fish output, we divide the volume vs. time function into equidistant parts and calculate the average volume for each part. In control, comparing this average values with the volume of available tank we can plan the appropriate stages. In design, we can repeat the same process with various possible tank volumes.

5. Implementation and testing of the developed solution

5.1. *Implementation of the “Extensible Fish-tank Volume Model"*

Let variable $V(t)$, m^3 the changing volume of the fish, nutrient, waste, etc. containing fish tank, where we want to keep a constant (or stepwise constant) stocking density ρ, kg/m^3, and let variable $M(t)$, kg is the changing mass of fishes in the tank. In the Extensible Fish tank Volume Model the $V(t)$ is calculated from $M(t)$ and ρ as follows:

$$dV(t)/dt = (1/\rho) * (dM(t)/dt) \quad (7)$$

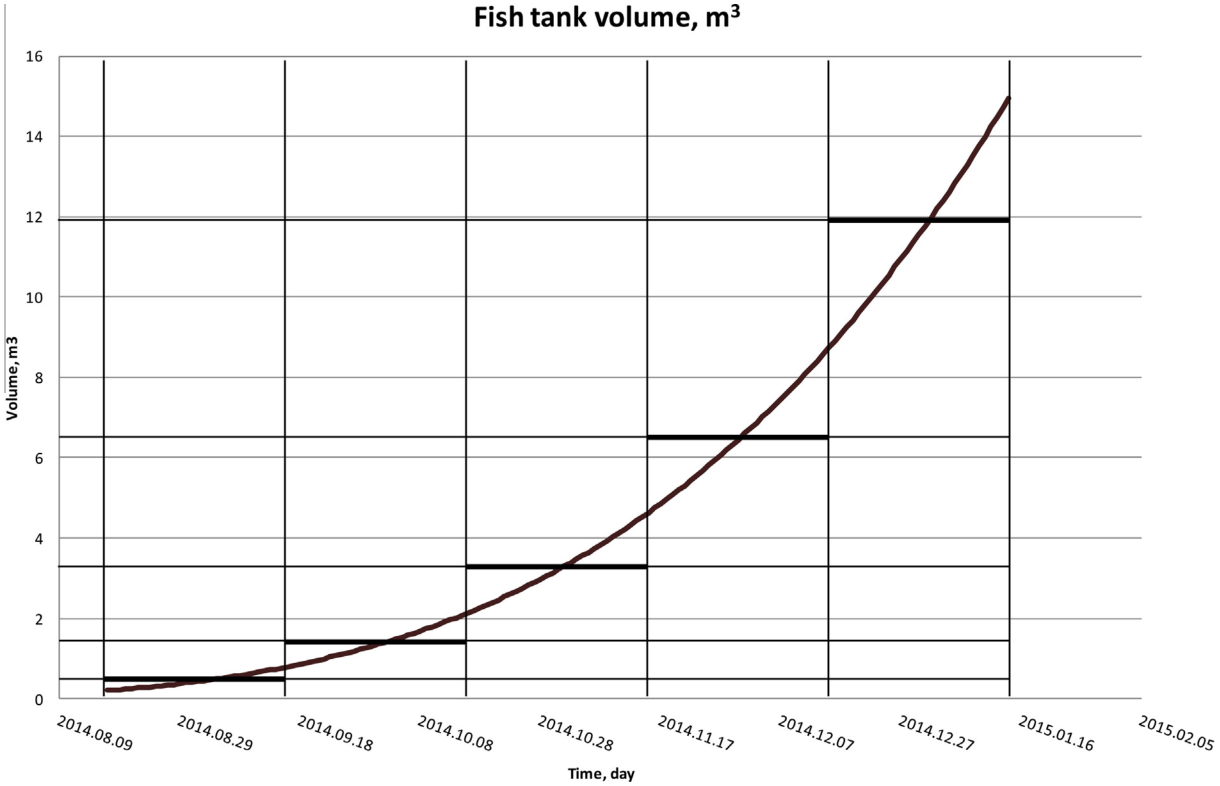

Fig. 6 – Simulated volume and discretization of the grades for constant stocking density of 300 kg/m^3.

The Extensible Fish-tank Volume Model can be implemented, as follows:

(a) Prescribe the stocking density, as the function of average fish weight.
(b) Extend the local model of the fish-tank with a brief part (that with the knowledge of the actual average mass of fishes and of the prescribed stocking density) determines the necessary volume of the "extensible fish-tank" in each time step. The volume of the fish-tank is modified accordingly.
(c) The control of input and output water flows is determined according to this continuously increasing volume.

In our first trials we applied two different prescriptions for the stocking density:

(a) Constant stocking density.
(b) Stepwise increasing stocking density, where in the first part (until a prescribed fish weight) we use a lower, beyond this weight a higher stocking density.

It is to be noted that any other optional stocking density vs. average fish weight function can be applied.

5.2. *Testing of "Extensible Fish-tank Volume Model"*

The simulated change of the fish-tank volume for the constant stocking density of 300 kg/m^3 is illustrated in Fig. 6.

In the simulation trials we calculated a single example fish tank in the RAS cycle. The technological parameters were the followings:

- number of fishes: 6000 pieces;
- average starting weight of fishes: 10 g;
- stocking density of fishes 300 kg/m^3;
- controlled nutrition level: 30 kg/m^3;
- water exchange: 3 m^3/day;
- efficiency of nitrification: 0.95;
- fresh water supply: 20%;
- number of grades: 5;
- total production period: 30 days.

We assumed, that 16% of fishes start with weight of 9 g, and 16% of them have an initial weight of 11 g, instead of the average 10 g.

In the calculation of the necessary volumes (or number of fish-tanks), according to the N grades we divide the curve into N (in this case $N = 5$) equidistant time slices. Next we calculate the integral mean value for each period (see bold black lines in Fig. 6. Finally, with the knowledge of the volume of the available fish-tanks the respective tank numbers can be determined. In our case, say, the volumes of the available fish-tanks are 0.5, 1 and 2 m^3. The respective system configuration is as follows:

Grade1: 2 tanks of 0.5 m^3,
Grade2: 3 tanks of 0.5 m^3,
Grade3: 3 tanks of 1.0 m^3,

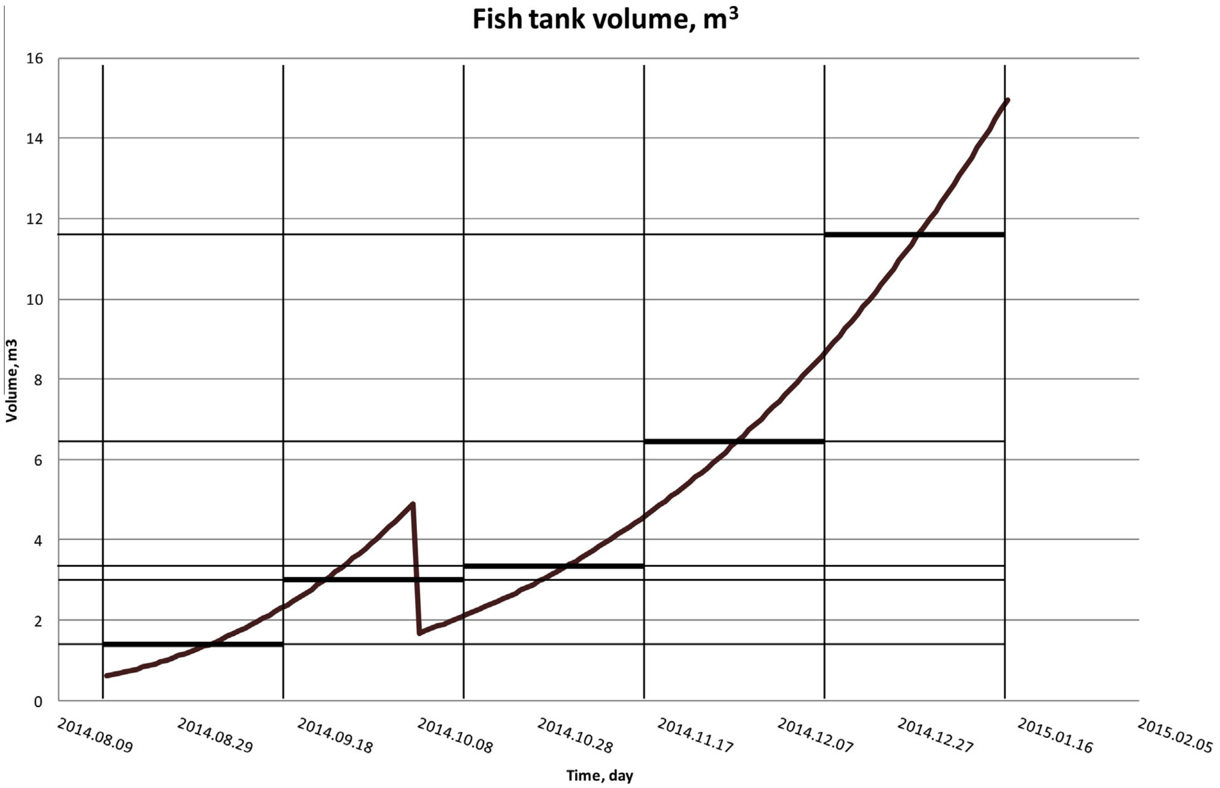

Fig. 7 – Simulated volume and discretization of the grades for stocking density of 100 kg/m^3 and 300 kg/m^3 before and after of a limit average weight of 84 g.

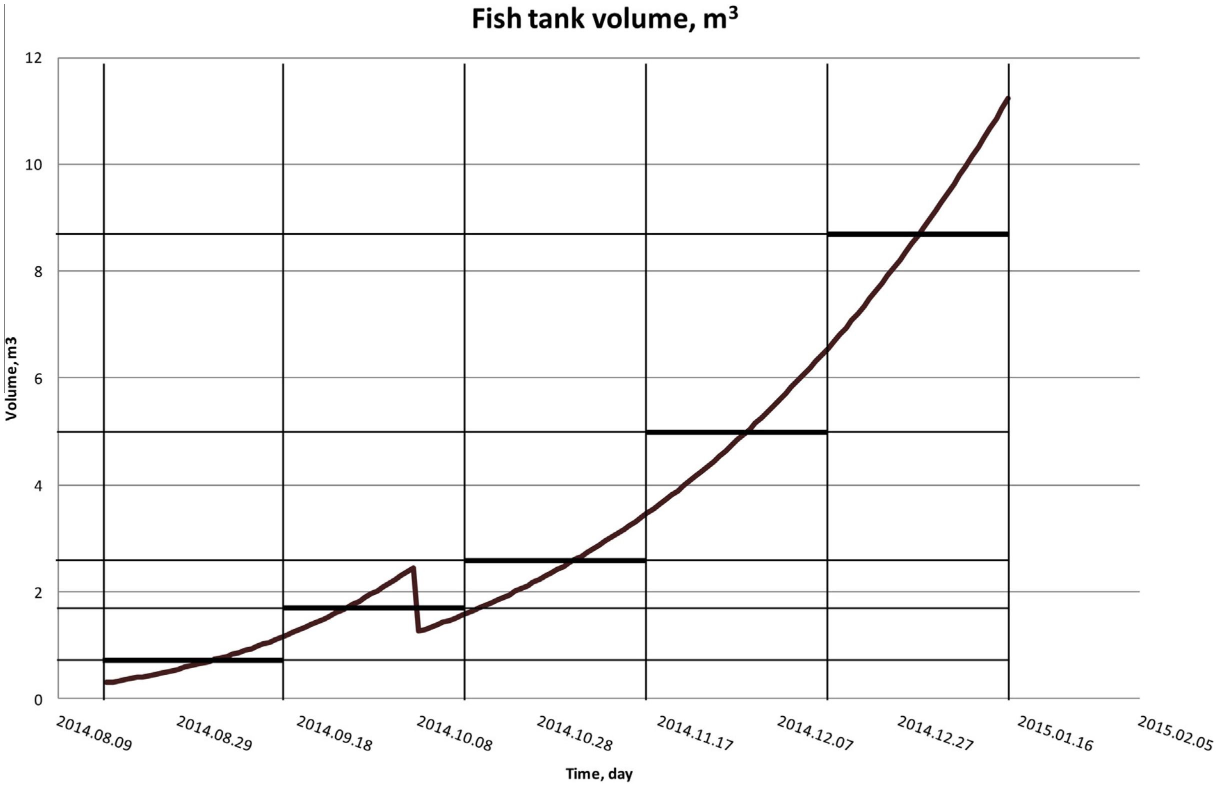

Fig. 8 – Simulated volume and discretization of the grades for stocking density of 200 kg/m^3 and 400 kg/m^3 before and after of a limit average weight of 84 g.

Grade4: 3 tanks of 2.0 m^3,
Grade5: 6 tanks of 2.0 m^3.

In the example, illustrated in Fig. 7, the stocking density until the average fish weight of 84 g is 100 kg/m^3, afterwards 300 kg/m^3. The respective system configuration is as follows:

Grade1: 3 tanks of 0.5 m^3,
Grade2: 3 tanks of 1.0 m^3,
Grade3: 3 tanks of 2.0 m^3,
Grade4: 3 tanks of 2.0 m^3,
Grade5: 6 tanks of 2.0 m^3.

In the example, illustrated in Fig. 8, the stocking density until the average fish weight of 84 g is 200 kg/m^3, afterwards 400 kg/m^3. The respective system configuration is as follows:

Grade1: 2 tanks of 0.5 m^3,
Grade2: 3 tanks of 0.5 m^3,
Grade3: 3 tanks of 1.0 m^3,
Grade4: 3 tanks of 2.0 m^3,
Grade5: 5 tanks of 2.0 m^3.

In the developed Extensible Fish-tank Volume Model we adjust the volume of a single fish-tank to the prescribed values of stocking density, by controlling the necessary volume in each time step. Having developed an advantageous feeding, water exchange and oxygen supply strategy, as well as considering a compromise scheduling for the fingerling input and product fish output, we divide the volume vs. time function into equidistant parts and calculate the average volumes for these parts. Comparing this average values with the volumes of available tanks we can plan the appropriate stages. Finally, having simulated the respective structure we can optionally refine the solution, iteratively.

Actually, we use a model controller and, in the fictitious Extensible Fish-tank Volume Model we adjust the volume of a single fish-tank to the prescribed value or function of stocking density, by controlling the necessary volume in each time step of the simulation.

6. Conclusions and planned future work

The elaborated methodology makes possible the preliminary design and planning of a RAS with a single fish tank model, that changes its volume according to the prescribed stocking density function (or value). We start the simulation with the prescribed stocking density of fingerlings, and in each time step of the simulation check the difference of the continuously increasing stocking density from the prescribed (constant or optionally changing) value. If the stocking density higher than the set point, then we calculate the surplus amount of the input water that dilutes the fish tank to achieve the set point of the stocking density. Simultaneously we increase the set point of the level for the calculation of the water output. With this surplus water inlet we can achieve the prescribed stocking density along the whole production from the fingerlings to the final product in a single (fictitious) fish tank. This make possible to decrease the complexity for the previous optimization, and also we can simulate and study the effect of the various stocking densities on the RAS process.

Having developed an advantageous feeding, water exchange and oxygen supply strategy, as well as considering a compromise scheduling for the fingerling input and product fish output, the volume vs. time function can be divided into equidistant parts and the necessary average volumes for the individual grades can be determined. Finally, for the solution of planning and control, with the knowledge of the volume of the available fish-tanks the actual system configurations can be determined. In design of new system, we can repeat the same process with various possible tank volumes.

In the following work we shall develop a detailed simulation based optimization example for a case, where having simulated the respective structures, the solutions will optionally be refined, iteratively.

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