Principle of construction and structure of an automated control system by underwater towed complex for ocean researchers

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1 Introduction

There are different methods of a self-tuning used in automatic control systems. In the main these are based on either a linear or a piecewise linear mathematical representation of a controlled plant. However not always it is possible to simplify a plant model to that extent. Then there is the only alternative to use a model based on a Software Simulator (SS). By means of the SS may be represented all substantial properties of a plant including such as a nonlinearity in parameters and distributed parameters. But apart from design problems of the SS there are principal difficulties of its application concerned with necessity to test model adequacy and tune the model parameters if necessary. These problems are solved as a rule by means of use of search procedures both in synthesis tasks and identification tasks. Naturally it requires considerable computational expenses that limits possibilities of application of software simulators in real-time control systems.

To overcome the difficulties it may be applied a technology of expert systems and a fuzzy mathematics for decision-making. The experience and the results of application of this approach in designing of the automated control system for the deep-sea research underwater towing complex are presented below.
2 Subject description

The Underwater Towing Complex (UTC) is a high complicated controlled plant which consists of the Tug, the Towing extended Cable-rope (TC) and the Underwater Vehicle in tow (UV) (see Fig. 1).

The chief object of the designed control system was to secure an accurate movement of the UV both on a given trajectory and about given target of an ocean bed. In that case the control problems are exceptionally difficult. We note only some.

The UV is not equipped in its own controls so movement control may be only proceed by use of the tug. The state of the UTC depends on many factors such as: dynamics of the TC and influence of a wind, sea currents and sea roughs. At the same time the TC has not any position sensors. By means of a hydroacoustic navigation may be only measured the tug position and the UV position. Thus we have a typical boundary value problem. Moreover we add a lack of reliable information about sea currents and an uncertainty in the mathematical model parameters and we receive a representation about the UTC as a controlled plant. The numerous sea tests have shown that on a manual control of the UTC movement it is impossible to receive an acceptable accuracy of executed manoeuvres.
3 Software structure

The structure of the automated control system software for the UTC is shown in Fig. 2.

The system may be fall in a class of hybrid expert system because it applies the software for simulation and so-called rule capture procedures for decision-making in a control. The joint application of the software allows both to expertise the model experiment and interpretation the UTC output data to produce a situation control.

The software simulator (SS) of the UTC is based on a numerical decision of dynamic equations for a flexible line in a water environment. The boundary data on the points of the line are defined by the movement lows both of the tug and the UV.

In this structure the SS acts as a predictor and it executes the following functions:

- produces the estimations of a relative position for the tug, the UV and the target,
- derives a fast and may be rather rough prediction of the UTC movement with the controls which are produced by means of the expert system,
- calculates errors between the predicted and real movement.

Figure 2
The expert system (ES) produces the controls being based on knowledge which have been accumulated during the preliminary investigations of the UTC both under the real conditions and on the mathematical model, and being used the errors between the predicted and the real UTC movement.

Unconditionally, an effectiveness of the hybrid expert control system depends on fullness and a base of knowledge quality, on the one hand, and depends on a presence of some information about external disturbances which affect the UTC, on the other hand. In addition, if disturbances affect on a boundary of an atmosphere and sea such as: a wind, seas, surface-sea currents, then it may be promptly compensated by the tug. But disturbances which affect on an underwater part of the UTC may not be promptly compensated. It is possible to compensate the disturbances only by means of a control based on a prediction.

In turn it is necessary to know the disturbance characteristics so as to predict successfully. Thus there is a problem of parameter identification of the software simulator for the UTC.

Besides, a qualitative prediction is possible, if there is some information about the current state of a controlled plant. In reality, because of random malfunctions of the hydroacoustic navigation, the automated control system has not full and accurate information about the UV position. Thus it is necessary to control by the UTC when there is not reliable information.

4 Fuzzy mathematics in a problem of parameter identification

In order to solve the parameter identification problem of the software simulator, the SS simulates the alternative variants of the UTC movement under the different conditions and at the same control during some time. The alternatives may be generated either unattended or attended by means of the system operator being based on some additional indirect information about the movement parameters of the UTC such as: a drift angle, a distance of the UV from track line of the tug and so on. By comparing the measurable position for the UTC and the calculated by means of the SS data, under the same initial conditions and controls it is possible to solve a problem of a minimization of an error function. For example, the error function during time at issue may be chose in the following form

\[ J(\alpha) = \frac{1}{n} \sum_{i=1}^{n} \left| X^i - X^i_m \right| + \left| Y^i - Y^i_m \right| + \left| Z^i - Z^i_m \right| + \left| L^i - L^i_m \right|, \]

(1)

where \( \alpha \) is the vector of tuning parameters; \( i \) is discrete time; \( n \) is quantity of the measurements at issue; \((X, Y, Z)\) are the UV position; \( L \) - is a length of the TC; \((X_m, Y_m, Z_m, L_m)\) are the simulated parameters respectively.

A minimization of the error function (1) may be carried out by means of using of search procedures in the model parameter state. But all exciting methods of an optimization are mainly local, but global optimization methods are only designed for special problems.
The researches have shown that the error function in the form (1) is a multimodal by virtue of nonlinear dependence from. So search procedures may not be applied for a global optimization of the function (1). Their application is advantageous at the final stage of an optimization.

The searching about a global minimum of the function (1) may be operated through an estimation of the alternative decisions which are generated by the SS. It is proposed to solve the problem by dealing with qualitative characteristics which describe the UTC movement in the 4-dimensional state XYZL. The proposed approach is based on an application of linguistic variables and a fuzzy logic.

We introduce the linguistic variables (LV) which will define the state of the UTC and we represent them as a triple \( \beta_m, T_m, X_m \), where \( \beta_m \) is a the names of the linguistic variables; \( T_m \) is their term-set; \( X_m \) is a general-purpose set. Let the set of LV contains the following linguistic variables:

- \( \beta_1 \) is "a distance from the UV to the tug"
- \( \beta_2 \) is "a deviation of the UV from the tug true course line"
- \( \beta_3 \) is "a length of the TC"
- \( \beta_4 \) is "a depth of the UV movement"

The term-set of the LV is the fuzzy variables which are formed from the sensor data by "fuzzying" of its values. So that the concrete value is a middle of a trapezium base which describes the membership function of the term in a simplification format L-R.

\[
T_m = \sum_{i=1}^{k} \mu_{T_m}^i(x), \quad x \in [x_{\text{min}}, x_{\text{max}}],
\]

\[
k = \text{card}(T_m),
\]

\[
x_{\text{max}} = \max(Y_m(t_j)), \quad j = 1, k,
\]

\[
x_{\text{min}} = \min(Y_m(t_j)), \quad m = 1, 4,
\]

where \( Y_m(t_j) \) is a numerical value corresponding \( \beta_m \) at some instant of time \( t_j \).

A range of the introduction variables LV and their term-set have been produced in the 1st experiment may be called as a fuzzy trajectory of the model.

The next step is construction of a fuzzy ratio in the term-set for the each LV:

\[
R_m^i = \sum_{i=1}^{k} \sum_{j=1}^{k} \mu_{m}^i(T_m^i, T_m^j) / (T_m^i, T_m^j),
\]

where \( \mu_{m}^i(T_m^i, T_m^j) = \mu_{T_m^i}^j(Y_m(t_i)) \).

An ensemble of the fuzzy ratios characterize a structure of the fuzzy trajectory for the 1st model experiment:

\[
S_i = \sum_{m=1}^{3} R_m^i.
\]
Similarly it is defined a structure of the fuzzy trajectory for the UTC. In this case only the sensor data are used. For calculation of an equivalence degree of the fuzzy trajectory structures is applied a fuzzy logic with limited operations:

$$\theta(S_1, S_o) = \bigwedge_{R_m \in S} \bigwedge_{(T_i, T_j) \in \tilde{S}^2_m} (1 - \left| \mu_m^l (T_i, T_j) - \mu_m^o (T_m, T_m') \right|).$$

The example of the estimation of the alternatives is shown in Tab. 1. Here the model results when the UTC has executed the complicated manoeuvres with different disturbances are presented. The 1st variant in the table is real data received during the sea tests.

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<th>Deep-Sea</th>
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<td>a direction (deg)</td>
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</tr>
<tr>
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<td>0</td>
</tr>
<tr>
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</tr>
<tr>
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<tr>
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</tr>
<tr>
<td>9</td>
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<td>290</td>
</tr>
</tbody>
</table>

Table 1

The correspondence rating under a decision-making is interpreted as a linguistic variable. Then in accord with the criterion (5) it may make that the 5th and 6th variants correspond to the linguistic label "good agreement", but the 7th variant correspond to the "bad agreement", although the latter is an optimal in accord with the criterion (1). In that case we must choose the 5th and 6th variants, but the 7th variant is admitted as a questionable.

The model tuning is an iteration procedure, so it is possible to modify a searching into the parameter state taking as a basis the received results.

5 Problem-solving base of knowledge for the UTC movement control

We consider a methods of a base of knowledge forming for the expert control system. The base of knowledge is used for a situation control of the UTC movement when a hydroacoustic navigation operation is unsatisfactory or on other occasions when it is impossible to tune the model and thus it is impossible to predict the UTC movement by means of it.

If the software simulator is actually by a plant model then the base of knowledge must realize the plant control based on the model. Since it is difficult
to acquire some knowledge about the UV control on account of a wide range of
the possible field conditions so an alternative approach is used. The approach
consists in induction of the accumulating knowledge by opening of cause-and-
effect relations when the control system has been operating.

For representation of some knowledge it is expedient to use a fuzzy
production system. In that case a discrete behaviour of typical condition-action
rules can be avoided and it is possible to maintain the control system in
operation when an introduction situation is not in agreement with the base of
knowledge contents.

We introduce the linguistic variables to characterize a control process:
- \( \beta_5 \) is "a distance from the target to the tug course line",
- \( \beta_6 \) is "a distance from the target to the UV course line",
- \( \beta_7 \) is "a difference in courses between the tug and the UV".

The ranges of change in the variables \( \beta_5 - \beta_7 \) must be connect with the TC
length in steady-state motion. For terms of the LV are designated as:

\[
\text{card}(T(\beta_i)) = 10; i = 5,7.
\] (6)

The membership functions of the terms are smoothed out among the change
range. The control is a discrete and it can take 3 values such as: "a starboard
circulation", "a portside circulation" and "a rectilinear motion".

The fuzzy situation is formed as follows

\[
S_o = \sum_{i=1}^{7} (\mu_S(y_m)/y_m),
\] (7)

where \( \mu_S(y_m) = \sum_{j=1}^{k} (\mu_{T_i}(y_m)/y_m). \)

The equivalence between the introduction fuzzy situation and the situation
from the base of knowledge is calculated by a formula

\[
\theta(S_o, S_k) = \text{&}_\beta \text{&}_{T_i} (1-|\mu_{T_i}(y_i^o)/y_i^o - \mu_{T_i}(y_i^k)/y_i^k|).
\] (8)

When it is a training operation then the prediction procedures are applied. In
that case it is necessary to know the parameters both of the model and an
environment. The control applied to the model is formed discretely in accord
with a decision-making interval under real conditions.

The input fuzzy situation is sequentially compared with left recursive
productions of the base of knowledge with the purpose of its identification. If an
agreement of the situation in the form (8) is not found both the input situation
and the control are wrote into the base of knowledge. The process is continued
as long as conditions of the experiment end will be satisfied. Then a control
object is reformed.

The base of knowledge filling is performed unattended while working of the
UTC automated control system and it may take several hours. An appearance
rate of new rules is a termination criterion. A total amount of rules may reach
hundreds.
In order to ensure adaptive properties for the control system it is possible to use a set of the bases of knowledge corresponding both to a substantially different parameters of the system and the active disturbances. To choose a concrete variant it may be applied the above-offered decision-making algorithm used for the tuning of the software simulator. It is possible to allocate invariant control rules which be correct in all situations.

6 Summary

Thus the chief idea being the basis for application of a fuzzy mathematics for the simulation data processing is founded on understanding that it is impossible to determine a full model adequacy for a complicated controlled plant. Simulation process is a naturally fuzzy. So for information processing of the simulation results it is expedient to apply a fuzzy set mathematics that allows to produce the qualitative estimations of different situations at a decision-making.

References

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