Development of algorithmic decision-making models for sea crews

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Abstract. Modern virtual simulators are multifunctional, i.e. they can be used to develop and enhance the skills as well as to control professional skills and abilities of specialists of diverse profiles under various working conditions. This study is based on the generalization of a large experience in the sphere of applying ready-made multifunctional virtual simulators (MFVS) and developing new ones for the training and retraining of the crews of the Azov-Black Sea fishing vessels. The model is implemented in the multifunctional visual simulator "Trawling and purse-seining" to train the situational awareness among navigators individually and in a team. Interviews with those who employ the graduates of the advanced training courses testify to the adequacy of this model.

1. Introduction

This study is based on the generalization of a large experience in the sphere of applying ready-made multifunctional virtual simulators (MFVS) of the crews of the Azov-Black Sea fishing vessels. It requires a special approach to training (to cope quickly with the task in conditions close to real ones in the waters of the Azov-Black Sea basin). At the same time, productivity depends on the coherent work of the whole crew and on the readiness of every specialist to perform his/her duties quickly and efficiently. The training of the cadets studying navigation, marine engineering and electric engineering in higher educational institutions is associated with the progressive formation of a large number of professional competencies required for purse seining.

This circumstance requires the urgent development of the MFVS in order to implement the workshops in various disciplines (courses). Modern professional MFVS available at the market are expensive and do not allow them to make changes that are necessary for the purposes and tasks of individual disciplines (courses). For this reason, special computer tools are required, which will allow the development and modification of the MFVS. Therefore, the topic of the thesis research devoted to the development of the MFVS for training crews of the fishing fleet vessels is of great concern, being very relevant and urgent at the same time.

2. Mathematical model of process sweeping

The linear velocity, with regard to its reduction in case of circulation, is expressed by formula (1), and the change in the relative bearing is written as differential equation (2).
\[ v = v_0 \cdot \left( \frac{0.015}{L_c - 3} + 1.162 \cdot e^{-T_c} + 0.045 \cdot tgL_c^2 - 0.157 \cdot e^{-16T_c} \right) \]  

(1)

\[ T_2 \frac{d^3\psi}{dt^3} + T_1 \frac{d^2\psi}{dt^2} + \frac{d\psi}{dt} - k_{c2} \sin^3 \left( \frac{\psi}{2} \right) = k_{c1} \left( a_p + \tau_1 \frac{da_p}{dt} \right). \]  

(2)

Here \( v_0 \) is the velocity in the position of the beginning of the cast; \( L_c \) is the relative length of the vessel; \( \psi \) is the relative bearing of the vessel; \( a_p \) is the rudder angle, \( k_{c2} \) is the coefficient taking account of the effect of the guide line. The numerical coefficients (1) are selected from the field trials.

Based on (1) and (2), a simulation model has been built. The results of experiments (Fig. 1) coincide with the data obtained in the course of field observations, with the permissible error respectively.

While casting the purse seine, the main parameters of the vessel change. After hauling the catch on board, the vessel changes its inertia features. In this case, there is a redistribution of the mass and the center of gravity of the vessel, which changes the moment of inertia of the vessel.

The process of identifying the parameters of the vessel’s model in the fishing situation. From (2):

\[ T_1 \frac{d^2\psi}{dt^2} + \frac{d\psi}{dt} - k_{c2} \sin^3 \left( \frac{\psi}{2} \right) = k_{c1} a_p. \]  

(3)

\( T_1 \) and \( k_{c2} \) are evaluated from the following equation system:

\[ k_{c1} \cdot \sum_{k=1,3,5} \frac{b_k}{k} \left[ \cos \left( \pi \cdot k \cdot t_2 / T \right) \right] = 0 \]

\[ T_1 = \frac{1}{\sin(\pi / t_2 / T)} \sum_{k=1}^{\infty} \left[ \frac{(\pi / T)^2 \left( 1 + (\pi T / T')^2 \right)}{\sin(\pi / t_1 / T)} + \frac{\cos(\pi / t_2 / T)}{\pi / T} \right], \]

(4)

where \( T \) is the period and \( t_2 \) is the time of the course zero deviation.

Expression (3) determines the nonlinear dependence, the Runge-Kut method is used to solve this equation. When splitting the process of casting the purse seine for time intervals of 1 second, authors assume that the input parameter (3) is constant within a given time interval, which allows us to proceed to a quasi-linear model describing the process of vessel motion during the shooting of the purse seine:

\[ T_1 \frac{d^2\psi}{dt^2} + \frac{d\psi}{dt} = k_{c1} a_p + M_{t-1}, \]  

(6)

where \( M_{t-1} \) is the turning moment due to the interaction forces of the vessel with the seine; \( a_p \) is the hard-over angle.

Then the solution of equation (6) with zero initial values \( (\psi_0 = 0, \psi'_0 = 0) \) is as follows:

\[ \psi_t = \psi_{t-1} - T_1 \left( M_{t-1} + k_{c1} a_{P_{t-1}} - \psi'_{t-1} \right) \left( 1 - e^{-\frac{1}{T_1}} \right) + M_{t-1} + k_{c1} a_p, \]

\[ \psi'_t = \left( \psi'_{t-1} - M_{t-1} - k_{c1} a_{P_{t-1}} \right) e^{-\frac{1}{T_1}} + M_{t-1} + k_{c1} a_p, \]

(7)
Produced recurrence relation (7) makes it possible to simulate the process of casting the purse seine with any diagram of the tension force of the guide line, and also for any law of rudder deflection. Field experiments carried out on board of the vessel in the course of casting the purse seine were confirmed by the experiments with simulation models (3) and (7).

To construct an imitation model of the movement of the fish schools, the following formulas are used:

\[
\frac{dx}{dt} = v_p(t) \cos(\psi_p), \quad \frac{dy}{dt} = v_p(t) \sin(\psi_p);
\]

\[
x(t) = \int_0^t v_p(\tau) \cos(\psi_p)d\tau \quad y(t) = \int_0^t v_p(\tau) \sin(\psi_p)d\tau \quad z(t) = H_p.
\]

(8)

To construct the imitation models of the vessel’s motion, the following formulas are used:

\[
\frac{dx}{dt} = v(t) \cos(\phi), \quad \frac{dy}{dt} = v(t) \sin(\phi);
\]

\[
x(t) = \int_0^t v(\tau) \cos(\phi)d\tau \quad y(t) = \int_0^t v(\tau) \sin(\phi)d\tau
\]

(10)

Figure 1 provides results of the functioning of the imitation model of the processes in the system “vessel – purse seine – target of fishing” for the various stages of casting the seine.

![Figure 1](image)

Figure 1. The imitation model of the processes in the system “vessel – purse seine – target of fishing”

a) t = 50 sec; b) t = 100 sec; c) t = 200 sec

Thus, a simulation model of processes in the system "vessel - purse seine - target of fishing" has been developed, which allows implementing training sessions for drilling skills of the purse seine shooting.

3. Implementing competencies

The simulator of the ship electric power system (SEPS) had been developing for 7 months, after which the experience was summarized and the software platform was produced [1-7]. The methodology designed to control the projects based on this platform, allowed one to reduce the development time for the simulator [5-8] to 5 months. By means of this methodology, two versions of the SEPS simulator were worked out to be implemented during various workshops, the time of their development and introduction into the educational process was 4 weeks.

For the MFVS to be developed, the functions of simulators were linked to professional competencies for the training of crews of fishing vessels: navigators (NAV), marine engineers (ME) and ship electrical engineers (EE). As it can be seen from Table 1, the functions of the SEPS simulator create and control a significant part of the professional competences taken from the educational
standards for these specialists. Assessment of competencies is carried out in the MFVS based on a repository of used cases (model solutions of tasks).

**Table 1.** Link of the SEPS simulator functions with the professional competencies of the specialists

| No. | Group of the simulator’s functions                                      | Specialist’s competencies |
|-----|------------------------------------------------------------------------|----------------------------|
|     |                                                                        | NAV | ME   | EE   |
| 1   | Typical methods of professional work with the automated SEPS           | PC1, PC2, PC3, PC4, PC-3, PC-4, PC-5, PC-22 |
| 2   | Techniques of professional work with the automated SEPS in conditions of switching stand-by generators | PC1, PC2, PC7, PC8, PC-7, PC-8, PC-9, PC-17, PC-11, PC-12 |
| 3   | Techniques of professional work with the automated SEPS in emergencies | PC1, PC2, PC18, PC-25, PC-26, PC-27, PC-28 |

Let us consider the evaluation of a trainee who undergoes individual training with the MFVS. Each used case for the appropriate individual task is a set of parameters, their reference values, rules for assessing the trainee's actions in control points (situations) \( s \in S \) and the permissible deviations of the parameter values from the reference points (%). The overall rating for the whole task is assessed as the average rating value for all control points of the task given. Figure 2 shows the scheme for developing tasks for various functions in the MFVS "Trawling and purse seining" [8-11].

![Figure 2. A scheme for developing tasks for training the skills in purse seining for navigators](image-url)
Let us further consider the evaluation of the real-time teamwork training within the MFVS. The use case for the teamwork task is a reference path of motion to the target (for example, a good shoot of the seine) by control points (situations) \( s \in S \), a set of parameters and their reference values, rules for evaluating the trainee's action in the control points (situations) and the permissible deviations of the parameter values from reference ones (%). Figure 6 shows the scheme by which the trajectory of team training in the MFVS "Trawling and purse seining" is controlled. As one can see in Figure 6, the actions of the navigator (the master of the crew) are variable. Their appropriateness and timeliness in the course of the discussion form the skills of situational awareness of oneself and other members of the crew.

4. Conclusion
The thesis study under review presents the outcome with certain scientific and practical implications:

A software platform was developed to control the multifunctional visual simulator projects, and, on its basis, a methodology was produced allowing reducing significantly the time of working out the MFVS (not less than 30% as compared to the development without its use). The methodology allows supporting the project of IMTF throughout the life cycle, quickly creating versions of web applications of this simulator for the purposes and tasks in the disciplines (courses). The methodology uses such chain of simulator models as the object, logical, ontological and information ones for the purpose of control.

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