Theoretical aspects of virtual simulators to train crews of fishing fleet

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Abstract. The use of virtual simulators is an important trend in the modern education, including the continuous training of specialists to meet the rapidly changing requirements for their qualification. 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 results of the experimental studies of the MFVS “Fishing Simulator for Trawling and Purse Seining” show that at least 10 sessions are required to develop sustainable purse seining fishing skills. Almost all trainees (95%) successfully cope with the task within the time permitted by the standard requirements (three minutes) after 15 sessions.

1. Introduction
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. This experience has been accumulated by the Training Simulator Center in Kerch State Maritime Technological University (KSMTU) located in the Republic of Crimea (hereinafter - in the Kerch Center).

Their training (retraining) is associated not only with the development of professional skills of navigators, marine engineers and electric officers in the context of constantly changing risk factors (wind, pitching, poor lighting, etc.), but also with achieving the major objective, i.e. teamwork skills that provide maximum profit as well as trouble-free service and accident-free operation of the commercial fishing fleet. Today, fishing vessels of the Azov-Black Sea basin use mainly two methods of fishing, namely trawling (60%) and purse seining (30%).

The former way, unlike the latter, is associated with the serious damage to the marine environment. Therefore, today the vessels are being re-equipped for purse seining. This process raises new tasks for comprehensive training (retraining) of crews of the Azov-Black fishing vessels. It should be noted that the effectiveness of purse seine setting is no more than 70% today, which indicates insufficient training of the crews of such vessels [1-3].

2. Statement of objectives and objectives of the study
The purpose of the paper is to develop and study the models, methods of algorithms for the elaboration
of the MFVS, which will cut the time of their creation and ensure the quality of professional training of the crews of fishing fleet vessels for fishing with purse seines. To achieve this objective, the following tasks were set and solved in the research:

1. Review and analysis of the experience in training navigators, ship’s engineers and electric engineers for the crews of fishing fleet based on virtual simulators.
2. Development of a software platform for the MFVS project management and development of a methodology aimed at reducing the complexity of its creation.
3. The development of the simulation model of the process for casting purse seines.

Methods of research. The methods of the probability theory, the set theory, the graph theory, the theory of artificial intelligence, as well as object-oriented programming technology, were used in the thesis research.

The object of the study is the training processes during the training (retraining) of navigators, marine engineers and electric engineers for fishing vessels.

The theoretical value of the thesis is to develop methods of mathematical modeling of technological processes for casting a purse seine on fishing vessels, as well as to produce models and techniques for the operational control of multi-functional virtual simulator projects for educational purposes and for the tasks of disciplines (courses) for training (retraining) specialists.

At present, more than 150 training centers that use various software and hardware training complexes (navigation simulators, GMDSS simulators, engine room simulators, simulators for cargo operations, etc.) are working in the sphere of training of water transport specialists in the Russian Federation. Analysis showed that their use was governed, first of all, by the International Convention on Standards of Training, Certification and Watchkeeping for Seafarers (STCW-78/95), in which the International Maritime Organization IMO established purposes and objectives of simulator training, aimed at the formation and control (evaluation) of specialists’ competences.

It has been established that at present, there are no virtual simulators for training professional skills and skills for safe and efficient fishing with a purse seine, as well as experience of operation when the ship's power supply system is baseload. This reason necessitated the tasks of developing two MFVSs. While creating these simulators, the specific features in interaction of all crewmembers (teamwork) should be taken into account, as well as the formed skills and abilities of specialists (navigators, ship’s engineers and electric engineers) and the professional competencies of educational standards should be related to each other. It is necessary to assess the competencies of trainees who have been trained individually and in a team.

It is shown that at present there are no models for steering the vessel in conditions of fishing with a purse seine. When these multifunctional visual simulators are developed and implemented, it is necessary to take into account the time limits for the purse seine casting and to ensure that the training of situational awareness of navigators contributes to the well-coordinated and efficient operation of the entire crew.

The working-out of any MFVS takes a long time (as practice shows, from six to twelve months). Its use in practice is subject to a variety of revisions, which are included in the pilot MFVS for one reason or another. It is necessary to develop a new simulator very often after re-equipment of the vessel. This shortens significantly the life cycle of the MFVS. In addition, one needs to create different versions of the simulators for their practical use in a particular academic discipline. Therefore, it is required to develop such software platform for project management of the MFVS which will allow one to organize the coordinated interaction of its developers (experts, programmers, designers), including the stage of making changes to the pilot MFVS. This requires a methodology that determines the procedure and rules for working with the software platform of all project participants.

3. Mathematical model
The methodology is based on the use of a software platform [1-7], developed with the participation of the doctoral student. Nowadays this platform is used in the Kerch Training Center for the development and maintenance of the MFVS hardware and software complexes. The platform (Figure 1) contains a
set of computer tools for developers and users of the simulator and allows supporting the creation and modification of the MFVS project at all stages of its life cycle. The project of MFVS has the following types of presentation: virtual environment, a logical model, an ontological model and an information model. Developers with such access rights as an expert, a designer, a programmer are involved in their working out and modification. The method consists of the following steps.

The domain expert, together with the designer, develops object models, which are then implemented by the programmer in the form of a virtual simulator environment.

1. The domain experts, using the logical model editor (LME), create a logical simulator model.
2. The domain experts, using the ontological model editor (OME), create the ontological model of the simulator.
3. The programmer, using the set of data components, creates an information simulator model.
4. After that, autonomous and complex testing is performed with an expert’s acceptance for use.

The model of objects is nonempty ordered set \( X = \{ x_1, x_2, \ldots, x_n \} \) with a partial order relation simulating the hierarchy of objects in the virtual simulator. Based on this set, a logical simulator model is constructed, which is oriented graph \( G(X, C) \), where \( C \) is an array of arcs modeling a particular type of links between objects (the type of link is established as an arc label). The logical model describes the structure of the simulator, being the basis for constructing its ontological model.

For the purpose of building the model, let us introduce the following sets (alphabets): \( D \) is the character set (an alphabet) of processes; \( Z \) is the alphabet of events; \( K \) is the alphabet of factors (environment, climate, time, etc.); \( P \) is the alphabet of competencies of a specialist (based on educational and professional standards); \( Y \) is the alphabet of the task complexity (from 1 for beginners to 5 for re-training of experienced specialists).

Let us have the nonempty set of functions for the simulator, \( F = \{ f_1, f_2, \ldots, f_m \} \). Explicitly, the ontological model of function \( f \in F \) is as follows: \( X(f), V(f), K(f), P(f), Y(f) \). Hereinafter, \( X(f) \subseteq X \) – a set of objects to implement the function, which creates within graph \( G(X, C) \) the subgraph, simulating the object model of the function; \( V(f) = \langle D, Z, I, U \rangle \) is a model that infers cause-and-effect relationships between processes and events in the simulator (I is an input function, U is an output function in the model); \( K(f), P(f), Y(f) \) are models setting up correspondence between this function of the model and factors, competencies and complexity respectively. The ontology-based model of function \( f \in F \) is used to generate various alternatives (instances) of function \( f^1, f^2, \ldots, f^k \), which are then implemented in the form of appropriate versions of tasks and use cases for their verification in the simulator. The ontological model of the simulator controls the development of its information model, after construction and debugging of which one or another working version of the web-based application, implementing the set of MFVS functions, is created. Any change in the project, caused, for example, by replacing out-of-date equipment on board of the vessel, does not result in the development of a new simulator “from scratch”. It is enough to change the model of objects, which will cause modification of all other models in the project chain of this simulator.

Thus, the proposed methodology applies a set of ready-made computer tools for the platform and involves building a chain of interconnected simulator models that allow controlling the interaction of its developers (experts, programmers, designers) to create a version of the MFVS.

The process of shooting the purse seine is the interaction of two “players”, namely the crew of a fishing vessel and the target of fishing (a shoal of fish). The main objective of the crew is to capture the target of fishing in a space limited to the seine. In this case, the parameters of the three-dimensional shell of the system “vessel-purse seine” should satisfy the certain conditions under which the target of fishing cannot escape the limits of the space bounded by the seine (Figure 1).
A mathematical model is proposed to describe the motion of a vessel when a purse seine is cast. Herewith, the effect of the resistant force of the guide line should be taken into account. 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).

![Figure 1. The path of the vessel on the turning circle without taking into account the tension force of guide line \((k_{c2} = 0)\) and with regard to tension force \((k_{c2} = 0.005)\)](image)

\[
v = v_0 \cdot \left( \frac{0.015}{L_c - 3} + 1.162 \cdot e^{-T_c} + 0.045 \cdot t g L_c^2 - 0.157 \cdot e^{-16L_c} \right) \quad \text{(1)}
\]

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

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 into account 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 (Figure 1) coincide with the data obtained in the course of field observations with the permissible error, respectively [9-12].

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.

4. Conclusion
A simulation model of processes in the system "vessel - purse seine - target of fishing" was developed. The results of experiments on this model were proved by field tests. This 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. After graduating such courses, navigators carry out efficient casting of purse seines within 3 minutes and this fact indicates their high professional expertise.

The results of the experimental studies of the MFVS "Fishing Simulator for Trawling and Purse Seining" show that at least 10 sessions are required to develop sustainable purse seining fishing skills. Almost all trainees (95%) successfully cope with the task within the time permitted by the standard requirements (three minutes) after 15 sessions.

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