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DEVELOPMENT OF AN OPTIMAL CONTROL MODEL FOR KNOWLEDGE RESTORATION IN MARINE NAVIGATORS

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In the dynamic and responsible profession of a marine navigator, the forgetting of skills and knowledge can pose a serious obstacle to ensuring safe navigation. The importance of maintaining a high level of qualification for navigators makes it relevant to develop effective methods for knowledge restoration and management of the learning process.

Thus, we are faced with the task of developing a mathematical model of optimal control for the navigator's knowledge recovery, which will consider the loss of qualification due to forgetting and the limited time available for learning.

Exponential decay is often used to model the loss of qualification due to forgetting. Suppose $x_i(t)$ is the proficiency index of the navigator in course *i* at time *t*. Let k_i be the forgetting coefficient for course *i*. Then, the formula for the loss of qualification due to forgetting for course *i* is as follows:

$$\frac{dx_i}{dt} = -k_i \cdot x_i(t)$$, where $i = 1, 2, ..., 12$

This equation describes how the navigator's proficiency in course i decreases over time due to forgetting. The coefficient k_i determines the rate of qualification loss and may depend on the characteristics of a particular course, as well as the individual features of the navigator.

It is important to note that a navigator may require continuous training or repetition of courses to maintain their qualification at a certain level. This can be considered in the model by adding a term that represents the process of learning or repeating courses:

$$\frac{dx_i}{dt} = u_i(t) - k_i \cdot x_i(t)$$, where i = 1, 2, ..., 12

Here, $u_i(t)$ is the effort that the navigator puts into learning or repeating course i at time t.

Suppose the navigator is executing a route on a vessel, and we know in advance (2-3 days) what knowledge needs to be restored to ensure safe navigation.

Suppose the development of a mathematical model for optimal control of a navigator's knowledge recovery is based on the need to possess the following knowledge:

1. The ability to continuously and attentively observe the surrounding environment, including the water surface, horizon, and airspace.
2. The ability to quickly notice and respond to changes in the surrounding environment and the movement of other vessels.
3. The ability to use radar, AIS (Automatic Identification System), GPS, and other navigation systems to determine the position, course, and speed of the vessel and other vessels.
4. The ability to interpret data from navigation instruments and use them for decision-making about vessel maneuvering.
5. The ability to identify and assess potential navigation hazards, such as meteorological conditions, currents, shoals, and underwater obstacles.

Let $x_i(t)$ be the proficiency index of the navigator in skill i at time t, where $i = 1,2,...,5$ corresponds to the skills listed above. The navigator wants to restore their knowledge to a certain level y_i for each skill i by the time T when they reach a critical point on the route.

We want to find the optimal control strategy $u_i(t)$ for each skill to maximize the navigator's proficiency in the most important skills by the time *T*, considering the time constraint for knowledge recovery and the loss of qualification due to forgetting.

Time constraints in the model of qualification loss due to forgetting:

$0 \le t \le T$, where *T* is the time to the critical point on the route (2-3 days)

Control constraints:

$0 \le u_i(t) \le U_{\max}$, where $U_{\max}$ is the maximum effort a navigator can invest in recovering a skill per unit of time.

Objective function:

$$J(u) = \sum \left[\left(y_i - x_i(T) \right)^2 \right]$$

The task is to find the optimal control strategy $u_i(t)$ for each skill to minimize the cost function J(u) and achieve the proficiency level y_i for each skill by the time *T*.

To solve this optimal control problem, dynamic programming methods such as the Bellman method [1], or the variational calculus method (Euler-Lagrange method) can be used [2].

As a result, the navigator will obtain an optimal control strategy for each skill, allowing them to recover their knowledge and ensure safe navigation at the critical point of the route.

To solve the optimal control problem using the Euler-Lagrange method, start by composing the Lagrangian *L* for our system:

$$L\left(x_i, u_i, t\right) = \left(y_i - x_i(t) \right)^2 + \lambda_i(t)\left(u_i(t) - k_i \cdot x_i(t) \right)$$

Here, $\lambda_i(t)$ are the Lagrange multipliers corresponding to the system dynamics equations. We need to find the extremum of the action functional:

$$S = \int L\left(x_i, u_i, t\right) dt$$

For each skill *i*, apply the Euler-Lagrange equations:

$$\frac{\partial L}{\partial x_i} - \frac{d}{dt}\left(\frac{\partial L}{\partial\left(\frac{dx_i}{dt} \right)} \right) = 0$$

Substitute the Lagrangian *L* into the Euler-Lagrange equation:

$$\frac{\partial}{\partial x_i}\left(\left(y_i - x_i(t) \right)^2 \right) - \frac{d}{dt}\left(\frac{\partial}{\partial\left(\frac{dx_i}{dt} \right)} \left(\lambda_i(t)\left(u_i(t) - k_i \cdot x_i(t) \right) \right) \right) = 0$$

Differentiate with respect to x_i and $\frac{dx_i}{dt}$:

$$-2\left(y_i - x_i(t) \right) + \frac{d}{dt}\left(\lambda_i(t) \cdot \left(-k_i \right) \right) = 0$$

Now, take the derivative of the Lagrange multipliers $\lambda_i(t)$ with respect to time and solve for $u_i(t)$:

$$u_i(t) = \frac{1}{k_i}\left(\frac{d\lambda_i(t)}{dt} + 2\left(y_i - x_i(t) \right) \right)$$

Now we have the optimal control $u_i(t)$ for each skill *i*. We are left to solve the system dynamics equation with the found controls:

$$\frac{dx_i}{dt} = u_i(t) - k_i \cdot x_i(t)$$

Integrating this equation, we will obtain trajectories $x_i(t)$ for each skill. Initial conditions $x_i(0)$ and boundary conditions should be set to obtain a complete solution.

Based on this model and having pre-known requirements for the navigator's skills at a certain point of the route, the task of developing a mathematical model of optimal control for the recovery of the navigator's knowledge was completed. This model will maximize the navigator's proficiency in the most important skills, ensuring safe navigation and optimizing the time for knowledge recovery.

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СУЧАСНИЙ СТАН І ОСНОВНІ ЗАВДАННЯ ПІДГОТОВКИ КАДРІВ У ВУЗАХ МОРСЬКОГО ТА РІЧКОВОГО ПРОФІЛЮ В УМОВАХ СТАНОВЛЕННЯ ІННОВАЦІЙНОЇ ЕКОНОМІКИ

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В даний час (за даними сайту osvita.ua) - підготовку фахівців з вищою освітою для транспортного комплексу України здійснюється на базі 20 галузевих вузів, що знаходяться у віданні міністерства освіти України

для залізничного транспорту 8 вузів, для повітряного транспорту - 14 вузів та для морського та річкового транспорту -8 вузів.

Найважливішою частиною системи галузевої підготовки кадрів вищої кваліфікації для вітчизняного та світового транспортно-дорожнього комплексу є вищі спеціальні навчальні заклади морського та річкового профілів, які здійснюють підготовку фахівців. У вузах, що готують фахівців для водного транспорту України, ведеться підготовка більш ніж за 20 напрямками та спеціальностями,