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The Linear Assessment Model for Navigational Factors

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Abstract: A linear mathematical assessment model for such navigational factors as bearing, heading angle and distance is described by the example of ship handling. These factors are used by operator for decisions on controlling a complex engineering system such as sea-going vessel. The mathematical model takes into account the psycho-emotional state of operator in the moment of decision making. While working out this mathematical model, authors used linear regression analysis and galvanic skin response as basic methods. They give the results of computer experiment on handling a ship while a relatively movable object was moving. The findings show the adequacy of developed model of reality. The linear assessment model for navigational factors can be used for working out a mathematical model of controlling an "operator-ship" system and creating an intellectual system for ship handling.

Key words: Complex engineering system · Human factor · Ship · Galvanic skin response · Electrical skin resistance

INTRODUCTION

"Operator-ship" systems belong to complex man-machine systems. In these systems, controlling decisions are made against the background of operator's psycho-emotional state. That is why the need for formalizing human factor arises while modeling such systems. At present, we note the excessive interest in the role of this factor in controlling complex engineering systems and ensuring safe running.

The real-world case described in [1] is a classical example of how human factor influences the safety of ship traffic. The share of this factor is more than 50% of other factors of safe traffic. As reported by International Maritime Organization, the safety and security of life at sea, marine environment protection and more than 90% of world trade depend on the professional competence of seamen, i.e. also human factor [2].

Human factor is characterized by the following notions:

- Operator's psychological qualities;
- The level of professional competence;
- Experience.

Human factor is studied from the point of view of these notions. Generally, this research line is based on psychology. As a result, they work out rules and regulations for human behaviour in real control of complex engineering system. That is, basically, they take into account the ergonomic aspects of "man-machine" system as an object for engineering and psychological investigations [3, 4].

MATERIALS AND METHODS

In comparison with the existing level of research, the findings make it possible to identify the role of human factor in controlling "man-machine" system. Research method used in this paper allows us to find out subjective regularities in controlling complex engineering system. This method is based on system approach to the assessment of operator's functional state and navigational factors. The fundamental principle of this method is the linear regression analysis of statistical data concerning operator's work and galvanic skin response (GSR) [5, 6].

Main Part: The assessment of navigational factors is an urgent problem in researching man-machine systems. Operator uses these factors to make decisions on

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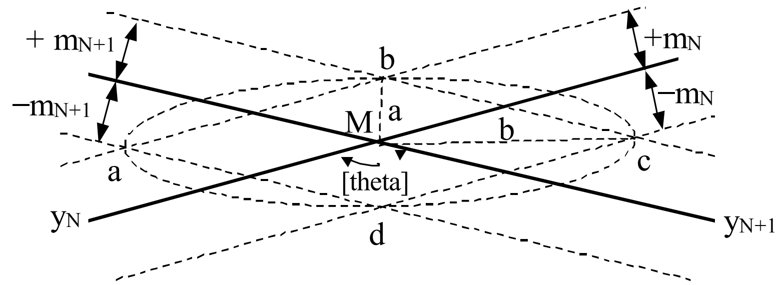

Fig. 1: The ellipse of dispersion.

controlling complex engineering system. Consequently, the quality of decisions depends on the psycho-emotional state of operator. That is why one should take human factor into account while assessing navigational factors. In the long run, the account of human factor will ensure the safe running of man-machine system, the quality of control and the creation of intelligent control system [7].

In order to identify navigational factors, we will study the system of equation known in ship handling theory [8, p. 58]. This system describes ship movement relative to manoeuvre object. On kinematic level, it has the following shape:

$$\dot{D} = V_o \cos B - V_s \cos HA;$$
$$D\dot{B} = V_o \sin B - V_s \sin HA,$$

where $\dot{D}$ is the rate of change in the distance between ship and maneuver object; B is bearing; V_s is ship's speed; HA is heading angle; D is distance; $\dot{B}$ is the rate of bearing's change.

Bearing, heading angle and distance characterize relative motion and the position of maneuvering object (ship) in relation to maneuver object on kinematic level. That is why these values can be used as basic navigational factors. Other values characterize the dynamics of movement and are not considered in this paper.

The research is aimed at working out a mathematical assessment model for navigational factors in controlling complex engineering system. Here are the mathematical formulation and the algorithm for research tasks.

The fundamental postulates are:

- The process of controlling decision making by operator consists in the assessment of random time function for each navigational factor. On its turn, random function is approximated (replaced) by a linear function. That is, decision making is linear.
- The moment of decision making is the cross-point of straight lines of relative linear functions. The coordinates of the cross-point can be found as the roots of the system containing two linear functions.
- The accuracy of decision making is assessed by the area of ellipse. The center of ellipse is in the cross-point of approximating lines, i.e. in decision making point.

Suppose, there is a random time function X(t) for some navigational factor. Chosen interval of X(t) is divided into N parts of length ΔT. For each N part there is an approximating linear function y = ax + b. The validity coefficient R^2 serves as a criterion for choosing N parts. If condition $R^2_N > R^2_{N+1}$ is met, linear function $y_N = ax + b$ is accepted as an approximating function on section N of random time function X(t).

Point M(x, y) where straight lines $y_N = ax + b$ and $y_{N+1} = ax + b$ cross corresponds to the moment of decision making on this navigational factor. Besides, the cross-point must be found inside the interval from ΔT_N to ΔT_{N+1}. If this condition is not met then sections N and N+1 unite.

The accuracy of point M(x, y) where straight lines $y_N = ax + b$ and $y_{N+1} = ax + b$ cross depends on the coefficient of approximation's validity R^2 for each line and angle of intersection [theta]. Then the accuracy of decision can be assessed by the area of figure abcd (Figure. 1). On Figure 1, m_N, m_{N+1} are the parallel shifts of approximating lines calculated with the help of the following formula:

$$m = \sqrt{S_{res}/n},$$

where S_{res} is the residual sum of deviation squares (it characterizes the deviation of experimental data yi from theoretical data y_i^t) that is calculated using the following formula:

$$Sres = \sum_{i=1}^{n} (y_i - y_i^t)^2;$$

n is the quantity of observations.

We suggest using the ellipse of dispersion for more strict assessment of decision accuracy. This ellipse has its center in point M(x, y) and is described around figure abcd. Ellipse's elements include: major semi-axis a, minor semi-axis b and angle [alpha] of the direction of major semi-axis in relation to the most accurate approximating line. The elements of ellipse can be calculated using the following formulae:

$$a \pm b = \frac{1}{\sin\theta}\sqrt{m_N^2 + m_{N+1}^2 \pm 2m_N m_{N+1}\sin\theta},$$

$$\operatorname{tg} 2\alpha = \frac{\sin 2\theta}{\frac{m_{max}^2}{m_{min}^2} + \cos 2\theta}.$$

We suggest using the following criteria for assessing navigational factors:

1. The frequency of decision making:

$$F = \frac{N-1}{\Delta T},$$

where ΔT is the time interval from the beginning of the test to the end.

2. The average area of total dispersion ellipse:

$$S_{av} = \frac{\sum_{i=1}^{N-1} S_i}{N-1},$$

where S_i is the area of dispersion ellipse for i-point of decision making that can be calculated with the help of the following formula:

$S_i = \pi ab.$

Let us consider the assessment criteria for operator's psycho-emotional tension. Galvanic skin response is used to register man's psycho-emotional tension. In the moment when a man makes a decision, we register a signal of electrical skin resistance R_i. This method is widely used in many spheres of researching man's psycho-emotional tension [9-12] and was used in our research.

The correlation of the signal with designed points of decision making (considering accuracy in the form of dispersion ellipse) gives us the opportunity to assess how human factor influences controlling on some navigational factor. It seems reasonable to use the relative value of electrical skin resistance signal R_i/R_{av} as an assessment criterion for human factor in decision-making points (R_{av} is the average value of electrical skin resistance signal for the whole test). Then, on the whole test, human factor can be assessed by the average relative value of this signal:

$$R_{rel} = \frac{\sum_{i=1}^{N-1}(R_i/R_{av})}{N-1}.$$

Experimental Part: In order to check the adequacy of the mathematical model, we conducted a computer experiment (test). We used computer ship-handling simulator as a "stimulus". The target of the test was to maneuver a ship in relation to a moving object. The maneuver was aimed at encircling a moving object at a safe distance. Moving object was free in moving.

While testing, such parameters of movement navigational factors as bearing, heading angle and distance were registered by discrete time intervals of 10 s. Controlling was designed as an angle of rudder. Simultaneously, during the whole test, we kept recording operator's galvanic skin response using instrument DIANEL-iON [13].

Experimental data are shown on Figure 2 in the form of diagrams. On these diagrams, navigational factors are shown in relatively dimensionless shape as relations F_{i+1}/F_i (F_{i+1} is the consequent value of navigational factor; F_i is the current value of navigational factor). Such presentation of experimental data makes it possible to compare and analyze various navigational factors. The initial values of navigational factors in relation to maneuver object are: bearing is 10°, heading angle is 10° and distance is 400 m.

The paths of ship and maneuver object during the test are shown on Figure 3.

The signal of electrical skin resistance is found with the help of GSR diagram. The moment of making decision was registered by the maximum swing in centinepers (cNp) [14].

In Table 1, there are summarized data in dimensionless shape for the whole test by each navigational factor: the frequency of making decisions F (the quantity of decisions made per time unit); the average area of total dispersion ellipse S_{av} in conventional units; the average relative value of electrical skin resistance signal R_{rel}.

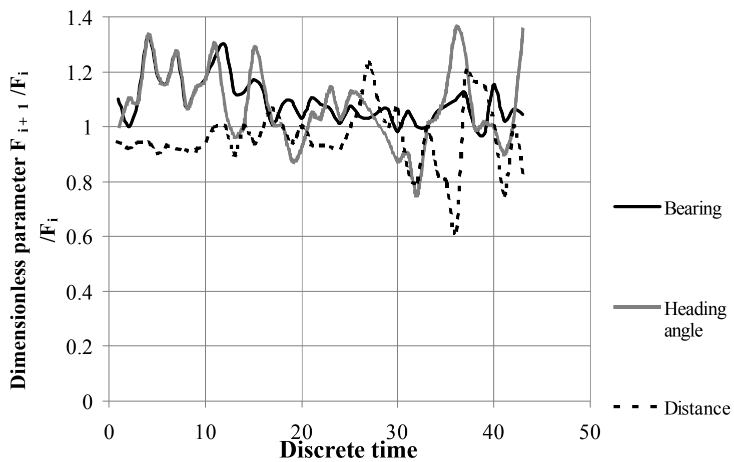

Fig. 2: Graphic presentation of experimental data

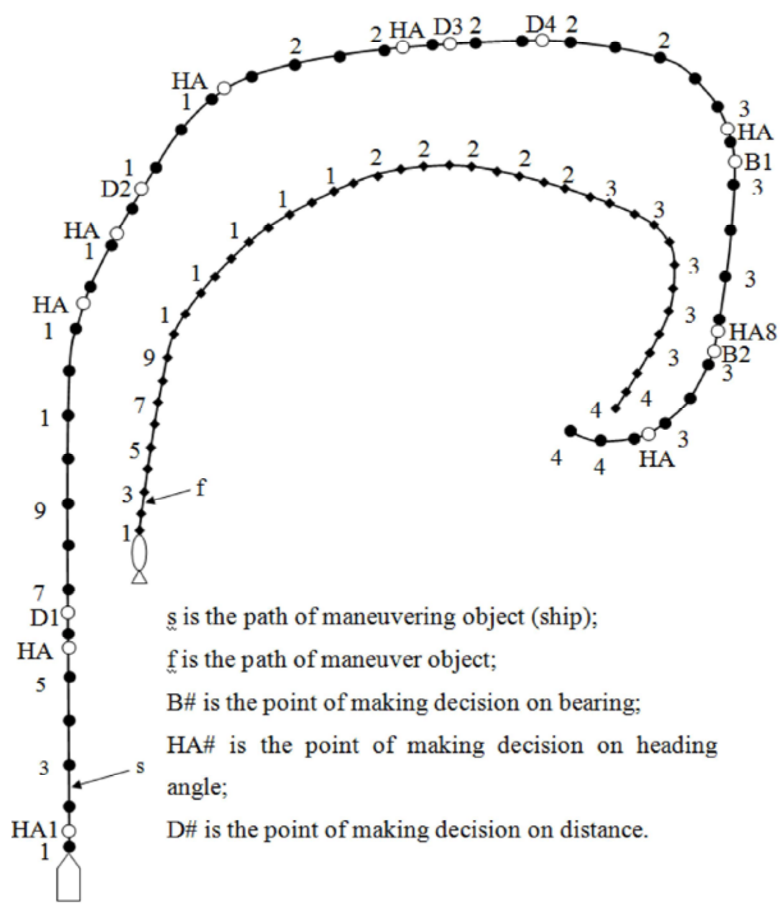

Fig. 3: The path of ship and maneuver object during the test

Table 1: Summarized data

Bearing			Heading angle			Distance		
F	S_{av}	R_{rel}	F	S_{av}	R_{rel}	F	S_{av}	R_{rel}
0.05	3.08	1.075	0.21	2.75	1.004	0.10	15.14	1.009

RESULTS AND DISCUSSION

Summarized data (Table 1) allow us to make the following conclusions. While handling a ship during the test, the operator made decisions mostly on heading angle (F = 0.21), then on distance (F = 0.10) and bearing (F = 0.05). The most accurate decisions were made on heading angle (S_{av}=2.75), then on bearing (S_{av}=3.08) and on distance (S_{av}=15.14). The average relative value of electrical skin resistance shows the level of operator's psycho-emotional tension in the moment of making decision. By this indication, the operator made deliberate decisions on heading angle (R_{rel}=1.004), then on distance (R_{rel}=1.009) and bearing (R_{rel}=1.075). At the same time, the average value of electrical skin resistance signal of the whole test was R_{av}= 316.66 cNp. The minimum value of this signal was observed at the first minutes of the test (R_{min}=262cNp) and the maximum value was observed in the end (R_{max}=375 cNp).

The analysis of findings allowed us to reveal the relation between decision making and psycho-emotional state of the operator. Besides, we managed to organize the considered navigational factors hierarchically. While handling the ship, the operator used heading angle, then distance and bearing as a main factor in the moments of making decisions. But the accuracy of decisions on distance is less than on bearing. As for the level of psycho-emotional state of the operator, deliberate decisions were made on heading angle, then on distance and bearing.

So, the results of the test show the adequacy of the linear mathematical assessment model for real navigational factors. The linear model described in this article makes it possible to structure and assess navigational factors. This model can be used to work out the mathematical model of controllability for "operator-ship" system and to create the intelligent system of controlling maritime vessels.

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