TRANSPORT SYSTEMS

CASE-BASED ASSESSMENT METHOD OF DETERMINING THE VAGUE BOUNDARIES OF SAFETY DOMAINS FOR THE JOINT MOTION OF VEHICLES

Information Technologies Department, Kherson National Technical University, Kherson, Ukraine
E-mails: 1vgherstyuk@gmail.com, 2marina.jarikova@gmail.com

Abstract—The case-based assessment method of determining the vague boundaries of safety domains in uncertainty situations using the rough set approach is considered. The construction of spatial configurations is described, method of determining the spatio-temporal similarity function is proposed. The proposed method is not sensitive to imprecise and incomplete observations due to using the rough sets to determine dynamic safety domains.

Index Terms—Ensemble of vehicles; joint motion; safety domain; blurred boundaries; activity trajectory; position; case; similarity function.

I. INTRODUCTION

Today complex technical systems have appeared containing a plurality of manned and unmanned vehicles working together according to established roles in a given mission. Such systems are called ensembles. The ensembles may include objects moving in different environments. For solving the variety of search and rescue tasks as well as military and emergencies counteracting tasks the ensemble can include aerial, overwater, underwater, ground and other types of vehicles.

One of the most important tasks of the ensemble activity is a joint motion of their vehicles. As a rule, the joint motion is limited by the space, by the given restrictions on the positional and functional structure of an ensemble, by the taken normative rules, and by the reaction of an environment, which gives rise to the different dynamic, navigation and situational disturbances into different points of space.

Nevertheless, the most important limitation of the joint motion is a guaranteed safety of vehicles and the problem of its maintenance is very essential. A growth of vehicles number and their size, a significant increase in their speed and density of movement within the confined space have lead to increase in the number of incidents and accidents, which in turn raises an important problem of ensuring a safe motion control.

Development of intelligent navigation systems is one of the most actively researched decision of this problem.

It should be noted that the development and practical realization of the tasks of complex vehicles’ ensembles motion control in real time are not currently worked enough, and have a great interest for research.

The most topical issue for today is to provide the intelligent onboard navigation systems for use in confined navigation conditions under the conditions of incompleteness and uncertainty of analyzed information, given a great amount of calculations with significant time limitations, in which poses significant risks and threats to vehicles’ safety.

II. REVIEW

Consider a set of vehicles \( U = \{u_1, u_2, \ldots, u_n\} \), such that each \( u_i \in U \) performs some activity in the confined space \( \Xi \) to achieve its goal \( G_i \in \Xi \). We assume that every goal \( G_i \) has a quantitative and/or qualitative description in \( \Xi \). Activity of \( u_i \) appears to perform a given program (plan) \( \Pi_i \), which is represented by a sequence of operations \( [\lambda_1, \ldots, \lambda_n] \) and brings it closer to the goal \( G_i \). In the course of the joint activity of vehicles some of them interact to others, forming a complex dynamic system \( \Omega \).

Many various models on risks and threat assessment have been previously proposed. The most common danger estimation method for rapprochement objects \( u_i \) and \( u_j \) is based on the definition of a linear (a distance to the closest point of approach \( D_{ij} \)) and temporary (a time to the closest point of approach \( T_{ij} \)) characteristics for the vehicles’ joint motion process [1]. Thus, danger assessment is based on the subsequent comparison of \( D_{ij} \) and \( T_{ij} \) with the given values of maximal
permissible distance of closest point of approach $D_z$ and the time remaining until the closest point of approach $T_z$.

Another approach [2] allows breaking down the circumjacent area into safe and dangerous areas (domains). In this case, we have to eliminate the ingress of any other objects into the domain as it moves. Therefore, any foreign objects intrusion into the domain boundaries will be qualified as a threat. As the development of this approach, two- and multi-dimensional domains having the shape of a circle, ellipse, and hexagon were proposed. It is clear that the shape and size of the domain depend on a set of factors of stochastic nature that make it impossible to determine domain boundaries [3].

The joint motion of the plurality of high-speed vehicles in confined spaces prevents the calculation of their correct security domains as well as the definition of threats based on predetermined maximal permissible limits becomes more difficult because the amount of computations increases exponentially. The situation is exacerbated by imprecision and incompleteness of available information. In addition, the stochastic effects of the environment makes little use of statistical methods.

In connection with these problems, in [4] the idea of "fuzzy boundaries" of domain was proposed, and in [5] this idea was developed to create a "fuzzy safety domain". The fuzzy domain is the space indicated around the vehicle that must hold free from the presence of the other objects. The size and shape of the fuzzy domain depend on the safety level considered as the membership degree of the current navigation situation to a fuzzy set of "a safe situations". Then, depending on the situation, we can select the minimum permissible safe level $\gamma$, which specifies the necessary domain boundaries.

Under the influence of above mentioned works it was suggested [6] that the terms of variables $D_z$ and $T_z$ would be represented as fuzzy, and the boundaries between them could be scaled depending on the number of factors. However, the "safe situations" fuzzy set's membership degree is expected to determine with any statistical or expert methods as well as the fuzzy evaluation of $D_z$ and $T_z$. This fact gives raise to the question of practical applicability of the above mentioned methods to the problem under consideration.

In [7] it is shown that the different models proposed to formalize the safe domains provide significantly different results, so they are not applicable in practice, and especially under the conditions of confined joint motion. Therefore, in [8] it is also concluded that an adequate description of vehicles joint moving process should take into account the more complex conditions of the safety approach and its stochastic nature, and further research of these issues is needed.

Thus, the bottleneck for safety assessment is the formalization of accepted safety assessment standards – the conditions of the closest approach or the safety domain boundaries. The absence of formal methods for the determination of these standards has resulted in unacceptable subjectivity in their meanings and significantly affected by the "human factor" in the safety.

III. PROBLEM STATEMENT

Suppose that an ensemble is formed of a group of vehicles in joint motion by applying some restrictions on their trajectories. The crisp formalization of the safety assessment methods is problematic, because they depend on the impact of a variety of factors, most of which have a stochastic nature, including dimensions, speed, maneuvering and inertial characteristics, errors of location estimate, weather and dynamic external impacts of disturbances, traffic density, etc.

In general, the use of fuzzy norms of safety assessments contradicts ensuring guaranteed safety. It needs the safety assessment to be close to 1 to achieve the goals but not hypothetical degrees of membership of the current situation to the fuzzy set of the "safety situations". Thus, the operators often use intuitive methods. However, in confined conditions they are limited in time to assess the situation, so decision-making requires intelligent decision support methods. A decision support system can get rid of informational and temporal overload of the operator and reduce dependence on its heuristic characteristics.

The aim of this work is to propose the method of risk assessment and threat detection, suitable for solving the problem of safety joint motion control for a plurality of vehicles under the confined conditions in real time and free of defects caused by the use of fuzzy sets as the tool for the uncertainty description.

We assume that using the rough set approach for the determining of the safety domains boundaries is more appropriate than the fuzzy one. This approach makes it possible to describe the blurred boundaries of the safety domains without attracting unwarranted statistical or expert assumptions. In addition, accounting the relative vehicles spatial positions makes it possible to describe the safety domains that have shapes different from sphere. Besides that, most characteristics of the vehicles interactions
should be represented as rough (blurred) norm limits, so we can use the case-based approach [9] to perform danger and threat assessment.

It is obvious that if we can collect proper norms for safety joint movement of the vehicles in some specified situations, we can use these norms as appropriate in the similar situations, and such collections may constitute a case base.

Thus, we propose a case-based approach to determine the vague safety domains for the set of vehicles in confined navigation conditions with incompleteness and uncertainty of analyzed information. In this paper, we formalize the description of the blurred safety domains and build a method of danger and threat assessment using the rough set approach and case-based techniques.

IV. SOLUTION OF THE PROBLEM

Let \( Y \) be a set of a certain nature, and let \( T \) be a set of time points. Consider a time scale imposed by a partial order \( <_T \) over time points from \( T \) with initial value \( t_0 \).

Suppose \( \Xi \) is a linear uniform space with respect to the norm \( \|v\| = \min_{t \in (0, T)} (v(t)), \) where \( y \in Y, \ t \in T, \) and \( \|v\| = \|v - y\| \) is an appropriate norm metric. Let \( C \) be a tree-dimensional space that contains the terrain of consideration. Suppose \( e_1, e_2, e_3 \) is a basis in \( \Xi \) such that the metric \( \xi_C \) remains uniform. Decomposition of some vector \( v = \alpha_1 e_1 + \alpha_2 e_2 + \alpha_3 e_3 \) gives a coordinates \( v(\alpha_1, \alpha_2, \alpha_3) \) in \( \Xi \). The coordinates of vehicle \( u_i \) represent its position in \( \Xi \) at the time \( t \in T \). The move of vehicles can be described adequately as changing their position in \( \Xi \) over the time \( t \), and consequently, as changing their coordinates in \( \Xi \).

Space \( \Xi \) is discretized by a grid \( D = \{d_{xyz} \} \) of isometric cubic cells \( d_{xyz} \), where \( x, y, z \) correspond to \( e_1, e_2, e_3 \) respectively. This allows switching from a continuous representation of \( \Xi \) to a discreet one. Thus, the vehicle's location in \( \Xi \) is discrete and bounds to a specific cell. Given the size of the cells can vary, the theater's scale can also change.

The main structural element of \( \Xi \) is a region \( H \), which has the following properties:

a) binding to the coordinates in \( \Xi \);

b) clarity;

c) uniformity in terms of the certain attribute's values.

Thus, the theatre \( \Xi = \langle D, h, \zeta \rangle \) is determined by the set of cells \( D \), the set of regions \( h \), and the linear isometric surjection \( \zeta: D \rightarrow h \). On this basis, each region \( H \) is approximated by an underlying set of cells \( H = \bigcup_{n_i} d_j \), where \( n_i \) is a total number of cells in \( H \). It should be noted that depending on the requirements \( \Xi \) can be associated with various sets of regions simultaneously. Therefore, one cell may map to a plurality of regions.

Now consider the vehicle's activity in \( \Xi \).

Each vehicle \( u_i \) performs the movement function \( f_0, \) and moves inside \( \Xi \) changing its position over the time and avoiding collisions with other vehicles.

Let \( Ps(u_i) \) be a position of vehicle \( u_i \) such that \( \langle Ps(u_i), t \rangle = \langle d_{xyz}, d_{xyz} \in D \rangle \), and let \( Crd(u_i) \) be a coordinates of vehicle in \( C \) such that \( \langle Crd(u_i), t \rangle = \langle \alpha_1, \alpha_2, \alpha_3 \rangle \). Then, a continuous sequence \( \langle Ps(u_i), t_1 \rangle \ldots \langle Ps(u_i), t_n \rangle \) at the time interval \( t \in [t_1, ..., t_n] \) is called activity trajectory, and is denoted by \( Tr(u_i) \).

At the beginning, the activity trajectory \( Tr(u_i) \) for each vehicle \( u_i \in A \) is prescribed by a mission plan \( Pl(u_i) \), which specifies important positions and performed functions.

However, due to unpredictable environments the vehicle is exposed to a number of dynamic and situational disturbances (overcast, weather conditions, as well as the results of activity of other members or opponents). Every disturbance \( \omega \) requires its compensation to minimize danger degree, which can range from changing the moving parameter(s) of activity trajectory to changing some positions that changes the trajectory itself [8].

The determining of the safety domains' vague boundaries can be performed using the following approach. The analysis showed that the fuzzy sets are weakly suitable for the closest approach conditions formalization as their membership functions depend on many factors, poorly formalized and make its construction by expert method impossible in real time.

Let us use the rough set approach to solve the problem. The uncertain conditions of the closest approach can be represented in a "rough" way based on the rough sets without any apriori information because the information about the area between their upper and lower approximations does not require assignment of a probability or possibility distribution or any membership functions.

For a consideration of the concept \( X \in U \) and a given equivalence relation \( R \) a lower approximation
The set of domains can be defined as

\[ B_j = \{ p_{i1}, \ldots, p_{ij}, \ldots, p_{mj} \} \] such that \( p_{i1} > p_{ij} > p_{mj} \).

Let us introduce a normed linear uniform space \( B_j \) for each \( u_j \), define the algebra \( \sigma_{B_j} \) and metric \( \xi_{B_j} \) similar to \( \xi_C \) such that \( \xi_{B_j}(d_j, d'_j) = \| d_j - d'_j \|_{B_j} \rightarrow P_j \), and surjective anisometry \( \lambda_j : C \rightarrow B_j \), which determines the subset of interacting vehicles.

We assume that \( u_j \) interacts with \( u_j \), if and only if \( \xi_{B_j}(u_i, u_j) < p_{ij} \). Accordingly, \( u_j \) interacts with \( u_j \) dangerously with danger degree \( k \) if \( \xi_{B_j}(u_i, u_j) < p_{ij} \), and interacts with \( u_j \) critically if \( \xi_{B_j}(u_i, u_j) \leq p_{mj} \). It is essential that the relationship \( \lambda_j \) is non-symmetric, i.e. \( \lambda_j(u_i, u_j) \neq \lambda_j(u_j, u_i) \). An interaction set \( A_j \) for vehicle \( u_j \) includes all vehicles in \( U \), which interact based on \( \lambda_j \) with at least one \( u_j \) such that \( u_i, u_j \in U \).

Given the \( \xi_{B_j} \) and \( P_j \) we can build a set of domains around each \( u_j \) starting from \( P_{s}(u_j) \) at each \( t \). For example, the set of domains can represent the domain of bounded activity \( H_j^1 \), the domain of hazardous activity \( H_j^2 \), and the domain of prohibited activity \( H_j^3 \), each of which generally is a sphere with a radius \( p_{j1}, p_{j2}, p_{j3} \) for \( H_j^1, H_j^2, H_j^3 \) respectively.

Since these domains are connected with a reference point \( P_{s}(u_j) \) that moves along the activity trajectory \( \text{Tr}(u_j) \), the domains \( H_j^1, H_j^2, H_j^3 \) also move inside \( \Xi \) together with the position of \( u_j \). Using non-linear and/or non-uniform metrics as well as fuzzy or rough sets’ methods, we can change the shape and blur the boundaries of built domains.

Based on \( P_j \) we can obtain some domain-dependent regions around \( u_j \) at each moment, each
of which are generally presented as a sphere with a center \( \text{Crd}(u_j) \) and radius \( p_{ij} \). Further, we can impose the space \( \Xi \) structure that divide this sphere into numbered or labeled sectors with a certain angular size, which are delimited by border lines with respect to \( p_{ij}, ..., p_{mj} \) as it’s shown in Fig. 3.

![Fig. 3. Spatial structure imposed for \( u_j \)](image)

Thus, the vehicle location is assigned to a concrete sphere sector and specified by its name.

If we assume that in different directions for different vehicles limiting safety norms can be established separately, taking into account the spatial configuration of the disturbances, we obtain the ability to define safety domains as shown in Fig. 4. As we cannot estimate boundaries of obtained spatial areas precisely due to dynamic environments, we describe these boundaries approximately using intervals of maximum permissible values posed by boundary regions of associated rough sets shown in Fig. 2. These intervals describe vague boundaries of spatial areas.

![Fig. 4. Determining non-sphere safety domains](image)

Danger and threat assessment can be performed in a following way. A joint activity of vehicles \( u_i \) and \( u_j \) is called mutually free if their trajectories \( Tr(u_i) \) and \( Tr(u_j) \) provide \( H^i(t) \cap H^j(t) = \emptyset \) in all positions. According to the trajectories \( Tr(u_i) \) and \( Tr(u_j) \) the activity of \( u_j \) is called limited for \( u_i \) if \( H^i(t) \cap H^j(t) \neq \emptyset \), \( k \)-dangerous for \( u_j \) if \( H^i(t) \cap H^j(t) \neq \emptyset \), and critical for \( u_j \) if \( H^i(t) \cap H^j(t) \neq \emptyset \).

It is clear that every critical activity is dangerous and every dangerous activity is bounding. If \( u_j \) limits the activity of \( u_i \), its domain \( H^i_j(t) \) is a dynamic restriction area for \( Tr(u_i) \).

The domain of possible activity \( H^i_j(t) \) for \( u_j \) excludes the areas of static and dynamic restrictions:

\[
H^i_j(t) = \Xi - \bigcup_{i=1}^{p} R_i^u - \bigcup_{j=1}^{m} H^u_j(t).
\]

Any interaction \( \lambda_{ij}(u_i, u_j) \) such that \( \xi_{ij}(u_i, u_j) < p_{ij} \) is called situational disturbance of activity trajectory \( Tr(u_j) \) with respect to \( u_i \) and is denoted by \( \omega_{ij} \).

Let us introduce a metric \( \xi_r \) on \( T \) such that \( \forall t_i, t_j, t_k \in T \):

\( a) \quad \xi_r(t_i, t_j) = 0 \iff t_i = t_j; \)
\( b) \quad \xi_r(t_i, t_j) = \xi_r(t_j, t_i); \)
\( c) \quad \xi_r(t_i, t_j) \leq \xi_r(t_i, t_l) + \xi_r(t_l, t_j); \)
\( d) \quad \| t_1 - t_2 \| \to P_j, \text{ where } P_j = \{ p_1, ..., p_y, ..., p_{mj} \} \)

is the time norm limit set.

Any interaction \( \lambda_{ij}(u_i, u_j) \) such that \( \xi_{ij}(u_i, u_j) < p_{ij} \) and \( \xi_r(A, A') \geq p_u \) is called a threat to \( u_j \) and is denoted by \( \omega^u_{ij} \). The threat is a dangerous disturbance requiring immediate unconditional compensation.

Thus, we can classify disturbances and build a spatial configuration as follows. We represent each disturbance \( \omega_{ij} \) as \( \omega_{ij} = \{ u_i, Pos(u_j), K_i \} \), where \( K_i \) is a certain class of \( u_i \). At each time point we have a vector of parameters for each \( u_i \) such that:

\( \bar{u}_i = \{ t, \text{Crd}(u_i), \vec{m}_i, v_i, \phi_i, \psi_{ij}, l_{ij} \} \), where \( \vec{m}_i \) is a velocity vector and \( v_i \) is its module, \( \phi \) is an angular velocity and \( \psi_{ij} \) is its module, \( \psi_{ij} \) is a bearing and \( l_{ij} \) is a distance from \( u_i \) to \( u_j \).

For each \( u_i \in U \) classification depends on its observed motion parameters and is performed...
separately as \( K_{ij} \) for each known \( u_j \). Thus, vehicles can be classified based on their motion parameters (altitude, velocity, and others) as “maneuvering / moving / stationary” at the moment, or as “moving closer / moving away / equidistant” at the time interval, or as “not dangerous / potentially dangerous / dangerous”. The total classification obtains by performing convolution operation as
\[
K_j = K_{i1} \oplus \ldots \oplus K_{in} \oplus \ldots \oplus K_{kn}.
\]

A tuple \( V_j(t) = (\omega_{i1}, \xi_{i1}, \zeta_{i1}), \ldots, (\omega_{in}, \xi_{in}, \zeta_{in}) \) defines a set of disturbances for vehicle \( u_j \) that are ordered with respect to \( \xi_{i1} \) (as \( \xi_{i1} \leq \xi_{i2} \leq \ldots \leq \xi_{in} \)). Now, if we distribute the disturbances spatially across the sectors of the safety domain, \( V_j(t) \) will be the spatial configuration for \( u_j \) at the moment \( t \in T \) as shown in Fig. 5.

![Fig. 5. Spatial configuration for \( u_j \)](image)

The spatial configuration for ensemble \( A \) is a composition of spatial configurations of its members, \( V(t) = V_1(t) \circ \ldots \circ V_m(t) \) [10].

V. IMPLEMENTATION OF THE CASE-BASED CONTROL OF THE SAFETY DOMAINS

The limit norms set necessary for building the safety domains can be obtained in a real-time intelligent case-based decision-support system as shown in Fig. 6.

![Fig. 6. Obtaining the boundaries of safety assessments by case-based reasoning](image)

The case structure includes a description of the navigation situation and corresponding vectors for an approximate estimation of safety domain boundaries. The search for a suitable case requires a given similarity function assessment for the observed situation with respect to the existing situations stored in the case base.

To build a similarity degree evaluation function we can use the well known nearest neighbor method based on measuring the coincidence degree for the case parameter values.

Consider a set of vehicles \( \{u_i, u_j, u_k, u_m\} \) from the position of \( u_i \) as it is shown in Fig. 7.

![Fig. 7. Determining the distances for \( u_i \)](image)

Suppose \( l \) is a distance function given on \( \Xi \) as
\[
l_{ij} = l(u_i, u_j) = \xi_c \left( Crd(u_i), Crd(u_j) \right).
\]

Let \( l \) has the following properties for each \( u_i, u_j, u_k \):

a) \( l(u_i, u_j) = l(u_j, u_i) \);

b) \( l(u_i, u_0) > 0 \);

c) \( l(u_i, u_i) = 0 \);

d) \( l(u_i, u_j) \leq l(u_i, u_k) + l(u_k, u_j) \).

The last formula defines the triangular inequality, and provides a condition for evaluating distances among vehicles based on metric relationship.

However, determining the distance \( l_{ij} \) between vehicles does not give a complete description of their spatial arrangement. This information is not enough to find spatially similar situations, because being at a similar points in \( \Xi \), vehicles can move with quite differing speed and in different directions.

The static component of the situation description should include bearings \( \psi_{ji} \) on the observed vehicles \( u_j \), as well as the movement vectors \( \tilde{m}_j \) can describe the observed dynamics of the situation defining direction and speed of vehicles’ movement, as it is shown in Fig 8.
The spatio-temporal description of the situation for $u_i$ should reflect the relative change of bearings and distances in time.

If we have $\text{Dest}_i(u_j) = \langle \text{Crd}(u_j), \phi_j, v_j, l_{ij}, \psi_{ij} \rangle$ at the time $t \in T$ and $\text{Dest}_i'(u_j) = \langle \text{Crd}'(u_j), \phi_j', v_j', l_{ij}', \psi_{ij}' \rangle$ at $t' \in T$ for some $u_j$, then we can obtain the relative changes of distances as $\Delta l = l_{ij}' - l_{ij}$ and bearings as $\Delta \psi = \psi_{ij}' - \psi_{ij}$.

The spatio-temporal description for each vehicle $u_j$ can be defined as $\text{Dest}_i(u_j) = \langle \text{Des}_i(u_j), \Delta l, \Delta \psi \rangle$ and spatio-temporal description of the situation for $u_i$ as $\text{Dest}_i = \langle \text{Des}_i(u_j), \text{Des}_i(u_k), ..., \text{Des}_i(u_n) \rangle$ where $n$ is a number of observed vehicles.

Using a spatio-temporal description $\text{Dest}_i$ of the situation for $u_i$, we can determine the value of a spatio-temporal similarity function $\text{SIM}_{ST}(u_i) = f(\text{Dest}_i)$ as proposed in [13].

Taking into account a huge amount of cases accumulated in the case base (Fig. 6), we can split similarity function as

$$\text{SIM}(u_i) = \text{SIM}_S(u_i) \oplus \text{SIM}_{ST}(u_i) \oplus \text{SIM}_E,$$

where $\text{SIM}_E$ is an environmental similarity.

The similarity degree $\text{SIM}_E$ is determined by comparing the wise situation's parameters to cases, whereby we can obtain the distance between the environmental parameters of the problem situation and the case situation as well as the maximal distance among them based on the parameters range [11]. If we find a case describing an environmentally similar situation based on $\text{SIM}_E$, we can distinguish a subset of cases relevant for the problem situation, and there can be a lot of such cases.

In the next stage, we can apply $\text{SIM}_S(u_i)$ to distinguished subset of cases and obtain a restricted subset of spatially similar situations as cases for similar environmental conditions.

Finally, we can find a subset of spatio-temporally similar situations stored as the cases using $\text{SIM}_{ST}(u_i)$. This subset will have a much smaller size, so that it is possible to identify the most similar situation effectively.

Further, we can use the values contained in the founded case as a solution for obtaining the blurred boundaries of the safety domains and for danger / threat assessing.
VI. CONCLUSION

We have proposed the case-based approach to obtain blurred boundaries for safety assessment where rough sets were used in uncertainty situations for describing spatial configurations. Due to using the rough sets to determine dynamic safety domains this approach is not sensitive to imprecise and incomplete observations. The main condition of proper implementation of this approach is the presence of a sufficient number of accumulated cases in case base.

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Information Technologies Department, Kherson National Technical University, Kherson, Ukraine.
Education: Kherson Industrial Institute, Kherson, USSR (1987).
Research interests: Intelligent control systems.
E-mail: v_sherstyuk@bigmir.net

Zharikova Marina. Candidate of Technical Sciences. Associate Professor.
Information Technologies Department, Kherson National Technical University, Kherson, Ukraine.
Education: Kherson National Technical University, Kherson, Ukraine (1999).
Research interests: Methods of Danger, threat and risk assessment.
Publications: 47.
E-mail: marina.jarikova@gmail.com

В. Г. Шерстюк, М. В. Жарікова. Прецедентний метод визначення розплівчатих меж безпечені областей у разі спільного руху засобів пересування
Розглянуто прецедентний метод оцінювання для визначення розплівчатих меж областей безпеки в ситуаціях невизначеності з використанням підходу на основі наближених множин. Описано побудову просторових конфігурацій, запропоновано способи визначення просторово-часової функції подібності. Запропонований метод є не чутливим до неточних і неповних спостережень внаслідок використання наближених множин для визначення динамічних доменів безпеки.
Ключові слова: ансамбль засобів пересування; спільний рух; область безпеки; розміті кордони; траєкторія активності; просторова конфігурація; прецедент; функція подібності.

Шерстюк Володимир Григорович. Доктор технічних наук. Професор.
Кафедра інформаційних технологій, Херсонський національний технічний університет, Херсон, Україна.
Адреса: Бериславське шосе, 24, Херсон, Україна, 73008
Напрям наукової діяльності: Інтелектуальні системи керування.
Кількість публікацій: 242.
E-mail: v_sherstyuk@bigmir.net

Жарікова Марина Віталіївна. Кандидат технічних наук. Доцент.
Кафедра інформаційних технологій, Херсонський національний технічний університет, Херсон, Україна.
Адреса: Бериславське шосе, 24, Херсон, Україна, 73008
Напрям наукової діяльності: Методи оцінювання небезпеки, загрози і ризику.
Кількість публікацій: 47.
E-mail: marina.jarikova@gmail.com

В. Г. Шерстюк, М. В. Жарикова. Прецедентний метод определяет расплывчатых границ безопасных областей при совместном движении средств передвижения
Рассмотрен прецедентный метод оценивания для определения расплывчатых границ областей безопасности в ситуациях неопределенности с использованием подхода на основе приближенных множеств. Описано построение пространственных конфигураций, предложен способ определения пространственно-временной функции сходства. Предложенный метод является не чувствительным к неточным и неполным наблюдениям вследствие использования приближенных множеств для определения динамических доменов безопасности.
Ключевые слова: ансамбль средств передвижения; совместное движение; область безопасности; размытые границы; траектория активности; пространственная конфигурация; прецедент; функция сходства.

Шерстюк Владимир Григорьевич. Доктор технических наук. Профессор.
Кафедра информационных технологий, Херсонский национальный технический университет, Херсон, Украина.
Адрес: Бериславское шоссе, 24, Херсон, Украина, 73008
Направление научной деятельности: Интеллектуальные системы управления.
Количество публикаций: 242.
E-mail: v_sherystvyk@bigmir.net

Жарикова Марина Витальевна. Кандидат технических наук. Доцент.
Кафедра информационных технологий, Херсонский национальный технический университет, Херсон, Украина.
Адрес: Бериславское шоссе, 24, Херсон, Украина, 73008
Образование: Херсонский национальный технический университет, Херсон, Украина (1999).
Направление научной деятельности: Методы оценивания опасности, угрозы и риска.
Количество публикаций: 47.
E-mail: marina.jarikova@gmail.com