TRANSPORT SYSTEMS

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

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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 are 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 $U = \{u_0, u_1, \ldots u_n\}$, such that each $u_i \in U$ performs some activity in the confined space Ξ to achieve its goal $G_i \in \Xi$. We assume that every goal G_i has a quantitative and/or qualitative description in Ξ. Activity of u_i appears to perform a given program (plan) Π_i, which is represented by a sequence of operations $[\lambda_1, \ldots, \lambda_k]$ 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 Ω.

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 γ, 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 Ξ is a linear uniform space with respect to the norm $\|y\|_c = \min\limits_{t\in[0,T)}\left(y(t)\right)$, where $y \in Y$, $t \in T$, and $\xi_C\left(y_1, y_2\right) = \|y_1 - y_2\|$ 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 Ξ such that the metric ξ_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 Ξ. The coordinates of vehicle u_i represent its position in Ξ at the time $t \in T$. The move of vehicles can be described adequately as changing their position in Ξ over the time t, and consequently, as changing their coordinates in Ξ. Space Ξ is discretized by a grid $D = \left\{d_{xyz}\right\}$ 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 Ξ to a discreet one. Thus, the vehicle's location in Ξ 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 Ξ is a region H, which has the following properties:

a) binding to the coordinates in Ξ;

b) clarity;

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

Thus, the theatre $\Xi = \langle D, h, \varsigma \rangle$ is determined by the set of cells D, the set of regions h, and the linear isometric surjection $\varsigma : D \to h$. On this basis, each region $H_k \in h$ is approximated by an underlying set of cells $H_k = \cup_{j=1}^{n_k} d_j$, where n_k is a total number of cells in H_k. It should be noted that depending on the requirements Ξ 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 Ξ.

Each vehicle u_i performs the movement function φ_0, and moves inside Ξ changing its position over the time and avoiding collisions with other vehicles.

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

At the beginning, the activity trajectory $Tr\left(u_i\right)$ for each vehicle $u_i \in A$ is prescribed by a mission plan $Pl\left(u_i\right)$, 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 ω 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

$POS_R(X)$ consists of all objects that must belong to the concept X and an upper approximation $NEG_R(X)$ consists of all objects that may belong to the concept X. The space between the lower and the upper approximations is the boundary area $BND_R(X)$ of the concept X, which consists of all objects that can not be unambiguously mapped to $POS_R(X)$ or $NEG_R(X)$ using knowledge available at the moment as it is shown in Fig. 1:

$$\underline{R}X = \cup\{Y \in U / R : Y \subseteq X\},$$
$$\overline{R}X = \cup\{Y \in U / R : Y \cap X \neq \varnothing\},$$
$$POS_R(X) = \underline{R}X,\ NEG_R(X) = U - \overline{R}X,$$
$$BND_R(X) = \overline{R}X - \underline{R}X.$$

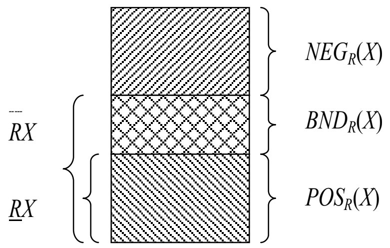

Fig. 1. Determining the areas of approximate sets

Thus, $POS_R(X)$ and $NEG_R(X)$ set the intervals, which contain the desired estimate values of safe boundaries with some accuracy $\alpha_R(X) = card(\underline{R}X) / card(\overline{R}X)$.

Getting aposteriori information about the values distribution can improve the accuracy of determining the concept X.

The boundaries of safety areas can be defined as approximate estimates of intervals specified by the boundary areas BND_{H1}, BND_{Hi}, ... BND_{Hm}, given that $POS_{H(i+1)} = NEG_{Hi} \cup BND_{Hi} \cup POS_{Hi}$ for each $H(i+1)$, for example as it is shown in Fig. 2.

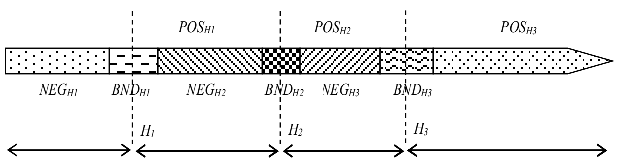

Fig. 2. Determination of the boundaries of spatial areas

Thus, for each vehicle $u_j \in U$ the controlled space is divided into the set of areas $\{H_j^1, \ldots H_j^i, \ldots H_j^m\}$ using approximate estimates of the safe boundaries $\{\tilde{D}_{jz}^0, \tilde{D}_{jz}^1, \ldots \tilde{D}_{jz}^l\}$. Now we need to find a way to assess $\{\tilde{D}_{jz}^0, \tilde{D}_{jz}^1, \ldots \tilde{D}_{jz}^l\}$, and as knowing them and assuming a constant vehicle speed at the current point in time, we can also determine the values $\{\tilde{T}_{jz}^0, \tilde{T}_{jz}^1, \ldots \tilde{T}_{jz}^l\}$.

For each u_j we define a set of norm limits $\mathrm{P}_j = \{p_{1j}, \ldots p_{ij}, \ldots p_{mj}\}$ such that $p_{1j} > p_{ij} > p_{mj}$.

Let us introduce a normed linear uniform space B_j for each u_j, define the algebra σ_{Bj} and metric ξ_{Bj} similar to ξ_C such that $\xi_{Bj}(d_1, d_2) = \|d_1 - d_2\|_{Bj} \to \mathrm{P}_j$, and surjective anisometry $\lambda_j : C \to B_j$, which determines the subset of interacting vehicles.

We assume that u_i interacts with u_j, if and only if $\xi_{Bj}(u_i, u_j) < p_{1j}$. Accordingly, u_i interacts with u_j dangerously with danger degree k if $\xi_{Bj}(u_i, u_j) < p_{kj}$, and interacts with u_j critically if $\xi_{Bj}(u_i, u_j) \leq p_{mj}$. It is essential that the relationship λ_j is non-symmetric, i.e. $\lambda_i(u_i, u_j) \neq \lambda_j(u_i, u_j)$. An interaction set A_j for vehicle u_j includes all vehicles in U, which interact based on λ_j with at least one u_i such that $u_i, u_j \in U$.

Given the ξ_{Bj} and P_j we can build a set of domains around each u_j starting from $Ps(u_j)$ 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_{1j}, p_{2j}, p_{3j} for H_j^1, H_j^2, H_j^3 respectively.

Since these domains are connected with a reference point $Ps(u_j)$ that moves along the activity trajectory $Tr(u_j)$, the domains H_j^1, H_j^2, H_j^3 also move inside Ξ 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 $Crd(u_j)$ and radius p_{ij}. Further, we can impose the space Ξ structure that divide this sphere into numbered or labeled sectors with a certain angular size, which are delimited by border lines with respect to $p_{1j},...p_{mj}$ as it's shown in Fig. 3.

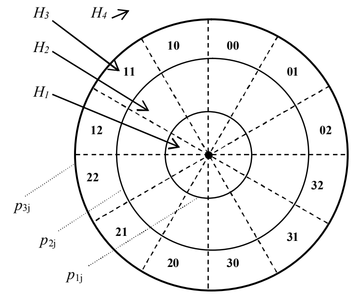

Fig. 3. Spatial structure imposed for u_j

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.

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 $H_i^1(t) \cap H_j^1(t) = \varnothing$ in

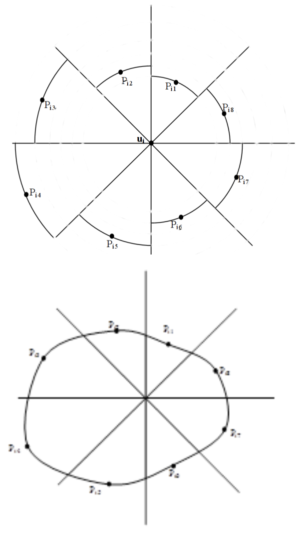

Fig. 4. Determining non-sphere safety domains

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 $H_i^2(t) \cap H_j^2(t) \neq \varnothing$, *k*-dangerous for u_i if $H_i^k(t) \cap H_j^k(t) \neq \varnothing$, and critical for u_i if $H_i^m(t) \cap H_j^m(t) \neq \varnothing$.

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 $H_j^1(t)$ is a dynamic restriction area for $Tr(u_i)$.

The domain of possible activity $H_j^*(t)$ for u_j excludes the areas of static and dynamic restrictions:

$$H_j^*(t) = \Xi - \bigcup_{k=1}^{p} R_k^S - \bigcup_{i=1}^{n} H_{ij}^m(t).$$

Any interaction $\lambda_j(u_i,u_j)$ such that $\xi_{Bj}(u_i,u_j) < p_{1j}$ is called situational disturbance of activity trajectory $Tr(u_j)$ with respect to u_i and is denoted by ω_{ji}.

Let us introduce a metric ξ_T on T such that $\forall t_i,t_j,t_k \in T$:

a) $\xi_T(t_i,t_j) = 0 \Leftrightarrow t_i = t_j$;

b) $\xi_T(t_i,t_j) = \xi_T(t_j,t_i)$;

c) $\xi_T(t_i,t_l) \le \xi_T(t_i,t_j) + \xi_T(t_j,t_l)$, and

d) $\|t_i - t_j\|_T \to \mathrm{P}_j$, where $\mathrm{P}_j = \{p_{1j},...p_{ij},...p_{mj}\}$ is the time norm limit set.

Any interaction $\lambda_j(u_i,u_j)$ such that $\xi_{Bj}(u_i,u_j) < p_{1j}$ and $\xi_T(A_i,A_j) \ge p_{1t}$ is called a threat to u_j and is denoted by ω_{ji}^*. 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 ω_{ji} as $\omega_{ji} = \langle u_i, Pos(u_j), K_i \rangle$, 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: $\vec{u}_i = \langle t, Crd(u_i), \vec{m}_i, v_i, \vec{\phi}_i, \varphi_i, \psi_{ij}, l_{ij} \rangle$, where $\vec{m}_i$ is a velocity vector and v_i is its module, $\vec{\phi}$ is an angular velocity and φ_i is its module, ψ_{ji} 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 $K_i = K_{i1} \oplus ... \oplus K_{ik} \oplus ... \oplus K_{iz}$.

A tuple $V_j(t) = \langle (\omega_{j1}, \xi_{T1}, \xi_{B1}), ..., (\omega_{jn}, \xi_{Tn}, \xi_{Bn}) \rangle$ defines a set of disturbances for vehicle u_j that are ordered with respect to ξ_T (as $\xi_{T1} \leqslant \xi_{T2} \leqslant ... \leqslant \xi_{Tn}$). 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.

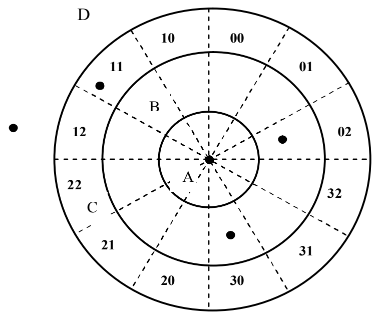

Fig. 5. Spatial configuration for u_j

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

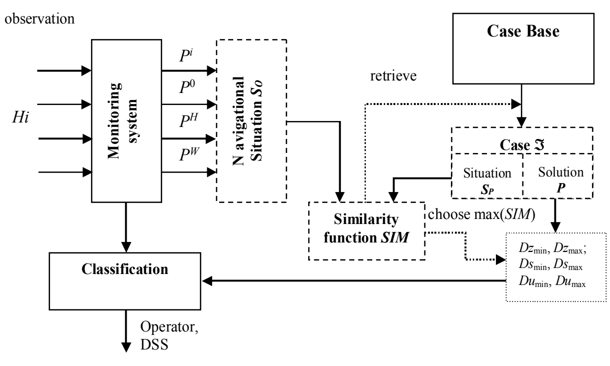

Fig. 6. Obtaining the boundaries of safety assessments by case-based reasoning

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.

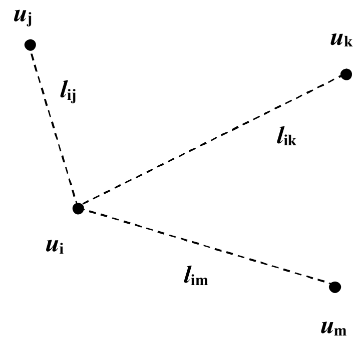

Fig. 7. Determining the distances for u_i

Suppose l is a distance function given on Ξ as $l_{ij} = l(u_i, u_j) = \xi_C(Crd(u_i), Crd(u_j))$.

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) $l(u_i, u_j) > 0$;

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

d) $l(u_i, u_k) \le l(u_i, u_j) + l(u_j, u_k)$.

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 Ξ, vehicles can move with quite differing speed and in different directions.

The static component of the situation description should include bearings ψ_{ji} on the observed vehicles u_j, as well as the movement vectors $\vec{m}_j$ can describe the observed dynamics of the situation defining direction and speed of vehicles’ movement, as it is shown in Fig 8.

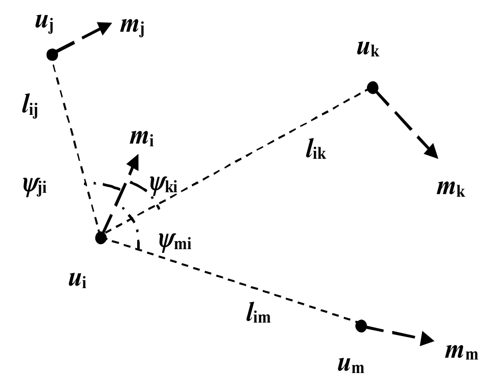

Fig. 8. Spatial description of the situation for u_i

The spatial description of the situation for u_i should enumerate other observable vehicles u_j with their coordinates $Crd(u_j)$, the calculated distances l_{ij} and bearings ψ_{ji}, as well as vectors of their movement $\vec{m}_j$, describing the direction ϕ_j and speed v_j. Thus, we have spatial description for each vehicle u_j as $Des_i(u_j)=\langle Crd(u_j),\phi_j,v_j,l_{ij},\psi_{ji}\rangle$ and spatial description of the situation for u_i as $Des_i=\langle Des_i(u_j),...Des_i(u_k),...Des_i(u_n)\rangle$ where n is a number of observed vehicles.

Using a spatial description Des_i of the situation for u_i, we can determine the value of a spatial similarity function $SIM_S(u_i)=f(Des_i)$ based on the nearest neighbor algorithm *iDistance* [12].

Since the boundaries of the safety domains strongly depend on the dynamic of the situation, we must also take into account the temporal component.

When vehicles moving in Ξ their distances and bearings are changing at different times as it is shown in Fig. 9.

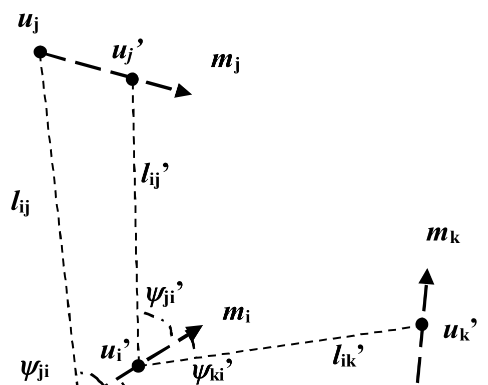

Fig. 9. Spatio-temporal description of the situation for u_i

The spatio-temporal description of the situation for u_i should reflect the relative change of bearings and distances in time.

If we have $Des_i(u_j)=\langle Crd(u_j),\phi_j,v_j,l_{ij},\psi_{ji}\rangle$ at the time $t\in T$ and $Des_i'(u_j)=\langle Crd'(u_j),\phi'_j,v'_j,l'_{ij},\psi'_{ji}\rangle$ 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 $Dest_i(u_j)=\langle\Delta l_{ij},\Delta\psi_{ji}\rangle$ and spatio-temporal description of the situation for u_i as $Dest_i=\langle Dest_i(u_j),...Dest_i(u_k),...Dest_i(u_n)\rangle$ where n is a number of observed vehicles.

Using a spatio-temporal description $Dest_i$ of the situation for u_i, we can determine the value of a spatio-temporal similarity function $SIM_{ST}(u_i)=f(Dest_i)$ 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

$$SIM(u_i)=SIM_S(u_i)\oplus SIM_{ST}(u_i)\oplus SIM_E,$$

where SIM_E is an environmental similarity.

The similarity degree 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 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 $SIM_S(u_i)$ 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 $SIM_{ST}(u_i)$. 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 was 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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В. Г. Шерстюк, М. В. Жарікова. Прецедентний метод визначення розпливчатих меж безпечних областей у разі спільного руху засобів пересування

Розглянуто прецедентний метод оцінювання для визначення розпливчатих меж областей безпеки в ситуаціях невизначеності з використанням підходу на основі наближених множин. Описано побудову просторових конфігурацій, запропоновано спосіб 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; розмиті кордони; траєкторія активності; просторова конфігурація; прецедент; функція подібності.

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В. Г. Шерстюк, М. В. Жарикова. Прецедентный метод определения 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.

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