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Using text models in navigation

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Abstract
In this work are described and researched methods of protection of navigation system from unauthorized attempts to substitute trajectory of moving objects, guided by radio or satellite. The proposed methodology to detect such interference in the operation of the navigation system is based on the use of data for historical, located on the premises trajectory.

Introduction

One of the most actual tasks of navigation is the task of autonomous moving object trajectory control. Moving objects can be of various types, which differ from each other by area of movement, on which the objects are orientated. Example of such objects are unmanned airplanes (*BPLA*), self-propelled wheel or track-type platforms, nautical vessels etc [1]. For convenience we will call such objects unmanned moving machine (*BRA*). In framework of solving the problem of *BRA* trajectory control, or navigation problem, arise necessity to solve following tasks:

- task of trajectory correction;
- task of trajectory control system protection or navigation system protection from unauthorized intrusion;
- task of location of current position of *BRA* in geophysical coordinates system, or current trajectory.

Task of trajectory correction arises as a result of the fact, that during movement of *BRA*, it is generally impossible to exactly follow the selected trajectory due to existence of various natural factors, which take place in the environment and lead to trajectory change. Currently, such task is solved by periodic check of real coordinates of *BRA* at the time t_i, which is implemented by various hardware means, depending on environment in which *BRA* moves.

Task of identification of current trajectory, or location of *BRA*, for different types of *BRA*, can be solved basing on checking of current trajectory, basing on use of landmarks in the environment, in which *BRA* is currently located. It is obvious that to solve this task *BRA* must be equipped by video devices, capable to register and recognize images of real landmarks [2]. In case when landmarks are absent, which is typical for nautical *BRA*, it is necessary to use other means like astronomy navigation etc [3].

Task of protection of navigation system from unauthorized intrusion is more complex and consists of the following parts, which are separate task themselves:

- task of activation of process of location of *BRA*;
- task of detection of fact of unauthorized intrusion into navigation system (*SN*);
- task of counteraction to intrusion into navigation system;
- task of neutralization of threat, which initiated unauthorized intrusion into navigation system.

Analysis of tasks of navigation system protection

The first and the second task, which should be resolved at the time of activation make the location

BRA in its environment motion detection and intrusion detection tasks in the Supreme Court are addressed in the following stages: during the organization of the mean *SN* are resolved in framework of following steps:

- the choice of initial activation time check the location of *BRA* in movement environment;
- detection of attack;
- prediction of time of following checks.

Method of initial activation is based on use of forecast model, which uses concept of random events. Such supposition is valid because one of important threat characteristics is its accidence. As a forecast model can be used regressive function [4]. Detection of threats is implemented basing on data about attack implementation by the threat. Most attacks on navigation systems are in attempt to substitute object's selected trajectory to other one. As we talk about autonomous objects, which function without pilot or navigator, then for threat implementation can be used control data transmission channel. Known attack on channels of satellite or radio connection is spoofing [5]. This kind of attack is implemented by substitution of real coordinates by ones, set by unauthorized source in satellite channel. Not depending on way of implementation of the attack, in general, aim of it is in unauthorized *BRA* trajectory change. So, identification of corresponding threat is less actual from the point of view of counteraction to the attack. Actuality of threat identification is only in case when exists task of threat termination. As we will not review this task in framework of this research, then we will stay on approaches to solve following tasks:

- detection of attack (*VA*);
- counteraction to attack (*PA*);
- protection from trajectory substitution attacks *BRA* (*ZA*).

Task of prediction of the period of next localization check of *BRA* will be resolved basing on results of solving tasks *VA*, *PA* and *ZA*.

Let us review task *VA*. For any kind of *BRA*, before its activation is formed trajectory of its movement, taking into account all known conditions in which movement will take place. In general, for *BRA* is formed description of the whole process of solving the task, set for *BRA*, but, in that case, we will limit ourselves with trajectory of movement. For *BRA*, which must function autonomously in framework of its onboard control system (*BSU*), there must be a description of movement trajectory. Such a description of the minimal variant must contain the following information:

- trajectory coordinates, which are discreet sequence, reflecting preset trajectory in natural for navigation system way;
- description of autonomous process of monitoring of trajectory aiming on check real localization of *BRA*;
- description of methods of counteraction to factors, leading to unauthorized *BRA* trajectory change.

Trajectory coordinates are mostly described as longitude and latitude point values according to geodesy rules [6]. In case, when *BRA* is unmanned airplane *BPLA*, or submarine, then coordinates system includes also altitude or depth respectively. Obviously, navigation system is equipped by devices, automatically measuring corresponding coordinates, which is performed during location check of *BRA*. Implementation of such methodic is based on use of trip computer, integrated with navigation system.

To resolve task of localization in case of autonomous movement on preset trajectory, navigation system must contain not only geodesy automated location hardware, but also additional data describing the environment in which moves *BRA*, which are static from the moment of preparation of the *BRA* for conducting the task and the time when the task is solved. Mostly, such data are called landmarks. Let us limit ourselves with landmarks, located on surface, and let us resolve tasks related to *BRA* of *BPLA* type. In that case, arises task of forming of description of landmarks, located in environment and description of links between landmarks and trajectory of *BPLA* movement.

Such landmarks are images that are registered by the recording and analysis of the environment of devices that belong to the system of environmental monitoring (*SM*) equipped with the *BRA*. Video cameras as the most common device for recording the environment, or in this case the camera with the possibility of registration of the visual environment images (*KVR*). In that case arises necessity to solve the following tasks:

- task of description of landmarks of environment, in which *BRA* is going to move;
- task of organization of connection between description of environment, in which *BRA* is going to move with description of this environment, formed by *SN* system;
- task of decision making on current modification by *SN* system of *BRA* trajectory.

We will be not reviewing the task of neutralization of threat, which activates intrusion of external factors into functioning of *SN*. Such intrusion is used to be called an attack [7]. This task is a task of counteraction of *SN* to attacks on itself and respectively on *BRA*. In case of necessity, to solving this task can be involved ground component of *BRA* group control system.

Let us focus on task of description of landmarks of the environment, where *BRA* of type *BPLA* moves. We will suggest that the landmarks are located on surface below the flight trajectory. We will combain landmarks with trajectory by geodesy coordinates of landmarks and flight trajectory.

Methodic of description of landmarks, corresponding to preset trajectory

To describe landmarks, located on *BPLA* flight trajectory, we will use a concept of text models (TM_i) which describes all landmarks and terrain type, above which is set fragment of flight trajectory, which we will call a possible localization check point *PPL* of relative *BPLA*. As far as landmarks of *PPL* are described, corresponding to flight trajectory, then their description is linked to corresponding images, being recognized by registration cameras. So, description of each landmark is made in such way, that this description would correspond to image, being registered by cameras system or separate *KVR* during *BPLA* flight above the landmark.

Text model is a description of corresponding landmarks and surfaces below *BPLA* flight. To identify corresponding *PPL* and corresponding trajectory point, are used timestamps of landmark identification, which correspond to estimated time of passing those landmarks during initial *BPLA* trajectory setup of corresponding *PPL*. During modification of trajectory and flight mode, values of timestamps are also subject to modification in description of corresponding TM_i. Totality descriptions of all *PPL*, over which trajectory is located, is a semantic dictionary (S_C), represented as:

$$x_1 = \{\langle a_{11} * \cdots * a_{1k}\rangle \langle p_{11}, \cdots, p_{1m}\rangle, t_i\}$$
$$\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots$$
$$x_n = \{\langle a_{n1} * \cdots * a_{nr}\rangle \langle p_{n1}, \cdots, p_{nq}\rangle, t_j\}$$

where: x_i – identifier of separate landmark described by text description $\langle a_{i1}*\cdots*a_{1j}\rangle$, where a_{ij} – word of user natural language, p_{ij} – parameter, characterizing relevant landmark x_i, t_i – timestamp of landmark x_i synchronization with flight time of *BPLA*, defined by preset trajectory. Descriptions will be marked as follows:

$$j(x_i) = \langle a_{i1} * \cdots * a_{ik}\rangle \langle p_{i1}, \cdots, p_{im}\rangle .$$

An example of p_{ij} parameter could be time lap Δt_i, during which *BPLA* must fly over x_i, if the last one is separate *PPL*, which is uniform surface fragment, for example terrain, covered by forest etc.

Such approach allows to describe trajectory by sequence of identifiers $\{x_1 \to x_2 \to \cdots \to x_n\}$ beside geodesy coordinates. Due to the fact that *BRA* movement towards target trajectory can change due to events in environment, then we will call the trajectory description as functioning strategy S_I, if the aim is movement of *BRA* to target point. Obviously, S_I describes all functions, used by *BRA* devices to reach the target. So, we can write down:

$$S_I = \{x_{i1} \to x_{i2} \to \cdots \to x_{im}\}.$$

Let us review fragment of the trajectory x_i which should be overcome during Δt_i time lap from the moment t_i until the moment t_{i+1}. In general case, $\Delta t_i \neq \Delta t_{i+1}$. For fragment Δh_{ij} from trajectory $H_i = \{\Delta h_{i1} * \Delta h_{i2} * \cdots *\Delta h_{im}\}$, basing on dictionary S_C is formed text model TM_i, which is a totality of text descriptions, describing landmarks, located along the trajectory H_i.

During monitoring system by a fragment of the system *SM* h_{ij} basing on image, registered by *KVR* is formed text description $TM_i(h_{ij})$ of fragment of landmarks h_i. Simple comparison of two text descriptions in that case is not valid because of following reasons:

- descriptions of $TM_i(h_{ij})$, formed basing on H_i are not completely adequate to real landmarks, as landmark data can be inaccurate and descriptions x_i in S_C can be incomplete;
- landmark images, formed in *SM*, or $TM_i(h_{ij})$ can also be inadequate to real images of landmarks due to distortions, appearing during registration and due to errors in image transformations $TM_i(r_{ij}) \to TM_i(h_{ij})$, where $TM_i(r_{ij})$ – description, formed by registrar.

So, arises task of definition of correspondence of physical localization of *BRA* with coordinates, set by flight trajectory. Solving this task by comparing relevant text descriptions is impossible due to mentioned above reasons. During solving this task it is necessary to not only detect differences between $TM_i(r_{ij})$, $TM_i(h_{ij})$, but also to define value of that difference. If value of difference is intolerable, then control system must calculate necessary correction of initial trajectory. As each *BRA* is moving on its own trajectory, then task of modification H_i must be solved in framework of system *BSU*. To ensure the ability of quantitative analysis of descriptions $TM_i(r_{ij})$ and $TM_i(h_{ij})$, corresponding text description are normalized and are introduced the following semantic parameters:

– semantic controversy σ^S;
– semantic conflict σ^K;
– semantic excessiveness σ^D;
– semantic inadequacy σ^N,

which are measured by separate x_i and x_j, which are neighbors in phrase or sentence. Because the pair of elements, between which can be measured value of semantic parameters, can be used phrases φ_i and φ_j, included into $TM_i(r_{ij})$ and $TM_i(h_{ij})$. Admissible values of semantic parameters are set basing on expert data, received after landmark images analysis. When creating the trajectory of movement, for each *BRA* is formed corridor of admissible deviations of geodesic location of *BRA* from preset trajectory. To describe the trajectory are included landmarks, located inside trajectory corridor boundaries. All landmarks, used in *SN*, are located in S_C.

Methodic of determination of value of *BRA* position deviation from preset trajectory

Methodic of determination of value of *BRA* position deviation from preset trajectory is based on use of text models. This methodic can be described as some sequence of points, describing steps of its implementation.

1. First sentence from $TM_i(r_{ij})$ and $TM_i(h_{ij})$ is selected.
2. Is selected a pair of components a_i and a_{i+1}, which are the words of elements x_i and x_j from dictionary S_C, or, are selected phrases φ_i and φ_j from $j(x_{ij})$, $j(x_{ir})$, depending on accepted starting conditions.
3. Is conducted synthesis of fragment from $TM_i(r_{ij})$ and fragment from $TM_i(h_{ij})$ in following way [8, 9]:
   – Is selected $x_i \in TM_i(r_{ij})$ and $x_{i+1} \in TM_i(h_{ij})$ from first sentences $TM_i(r_{ij})$ and $TM_i(h_{ij})$;
   – Are checked values of semantic parameters σ^S, σ^K, σ^D and σ^N for $x_i * x_{i+1}$;
   – If value of at least one parameters exceeds allowed threshold or $\Delta\sigma^i \leq \sigma^i$, then we go to paragraph 4;
   – If $\Delta\sigma^i > \sigma^i$, then we go to $x_{i+1} * x_{i+2}$, or to elements φ_j and φ_{j+1}, where $(\varphi_j \& \varphi_{j+1}) \in \psi_j$ and ψ_j is a result of synthesis of ψ_j^r and ψ_j^h with $TM_i(r_{ij})$ and $TM_i(h_{ij})$ respectively;
   – Process continues till the moment, when all sentences of $\psi_j^r \in TM_i(r_{ij})$ and $\psi_j^h \in TM_i(h_{ij})$ will not be analyzed, then we go to paragraph 6.
4. Is conducted analysis of geodesic coordinates g_i (y_{i1}, y_{i2}) going out of the trajectory corridor.
5. If g_i (y_{i1}, y_{i2}) went out of trajectory corridor, then decision on modification of strategy S_i of control of separate *BRA* is made. In other case we go to paragraph 1 after the end of time lap Δt_i from the moment t_i until the moment t_{i+1}, which define a separate step of *SM* job.
6. We go to paragraph 1 after time lap Δt_i.

Proposed method of determination of deviations of *BRA* position from preset trajectory ensures detection of influence of external factors on moving objects. As it was mentioned before, task of counteraction to such events requires a separate research, because it is not always reasonable to limit it to trajectory correction of *BRA* or S_i correction. Task of recognition of threat, activating relative factors and task of elimination of those threats also require separate research.

Conclusions

Proposed analysis of tasks of actual *BRA* position in movement environment shows, that its solution allows ensuring movement of *BRA* on preset trajectory while it is affected by factors preventing *BRA* from it.

In this research, it is accepted that negative factors can be activated by natural and artificial factors, which are called unauthorized factors, and respectively, those who make them are called unauthorized players of *BRA* system control and mostly the reviewed approach is orientated on detection of last ones [10].

Due to use of text models, describing landmarks, located inside preset trajectory corridor, it is possible to locate real position of *BRA* in environment of its movement. Basing on parameters, characterizing factors, leading to trajectory change, it is possible to determine sources of those factors. Such parameters include:

– regularity of factors influence;
– direction of *BRA* trajectory change during intrusion into movement control;
– intensity of negative factors influence etc.

Due to the fact, that detection of *BRA* position is based on use of landmarks and also due to use of electronic maps of various scale and detailing of artificial objects, located on surface it is possible to include into S_C additional landmarks, located on directions, to which one or another factor tries to change *BRA* trajectory. Such information can be used for making decisions by control system on solving the general strategic task, set for the system of moving objects group.

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