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[1]**P. I. Bidyuk,**
[2]**R. I. Manuilenko,**
[3]**R. L. Pantyeyev**

FILTERING ALGORITHMS FOR DETERMINING THE COORDINATES OF THE OBJECT IN DECISION SUPPORT SYSTEMS

[1]National Technical University of Ukraine "Igor Sikorsky Kyiv Polytechnic Institute", Kyiv, Ukraine
[2]Systems Control Theory Department, Institute of Applied Mathematics NASU, Slovyansk, Ukraine
[3]Aviation Computer-Integrated Systems Department, National Aviation University, Kyiv, Ukraine
E-mails: [1]pbidyuke_00@ukr.net ORCID 0000-0002-7421-3565, [2]ronma2016@gmail.com,
[3]romanpanteevmail@gmail.com ORCID 0000-0003-4707-4608

Abstract**—***Methods for estimating the parameters and states of dynamical systems are an urgent task, the results of which are used in various fields, including processes in technical systems, cosmological and physical research, medical diagnostic systems, economics, finance, biotechnology, ecology and others. Despite significant scientific and practical advances in this area, researchers in many countries around the world continue to search for new methods of assessing the parameters and states of the studied objects and improving existing ones. An example of such methods is digital and optimal filtering, which have been widely used in technical systems since the middle of the last century, in particular, in the processing of financial and economic data, physical experiments and other information technologies for various purposes. The model and algorithms of granular filtering are considered on a practical example - a variant of the problem of global localization of mobile robot (global localization for mobile robots) or the problem of hijacked robot (hijacked robot problem). In the general embodiment, it is to determine the position of the robot according to the data from the sensor. This problem was generally solved by a number of probabilistic methods in the late 1990s and early 2000s. The task is important and finds application in mobile robotics and industry. The tasks of positioning submarines, aircraft, cars, etc. are essentially similar.*

Index Terms—Parameter estimation; state estimation; dynamic system; granular filter; digital filtering; optimal filtering; non-systematic error; robot positioning; decision support system.

I. INTRODUCTION

Methods for estimating the parameters and states of dynamic systems are an urgent task, the results of which are used in various fields, including processes in technical systems, cosmological and physical research, medical diagnostic systems, economics, finance, biotechnology, ecology and others. Despite significant scientific and practical advances in this area, researchers in many countries around the world continue to search for new methods for estimating the parameters and condition of the studied objects and improving existing ones. An example of such methods is digital and optimal filtering, which have been widely used in technical systems since the middle of the last century, in particular, in the processing of financial and economic data, physical experiments and other information technologies for various purposes.

The model and algorithms of granular filtration are considered on a practical example – a variant of the problem of global localization of a mobile robot (global localization for mobile robots) or the problem of a hijacked robot problem. In the General embodiment, it is to determine the position of the robot according to the data from the sensor. This problem was generally solved by a number of probabilistic methods in the late 1990s and early 2000s. The task is important and finds application in mobile robotics and industry. The tasks of positioning submarines, aircraft, cars, etc. are essentially similar.

The problem of robot positioning is also considered. Let the robot turn on in the dark maze. It has a maze map and a compass. In the labyrinth at some points there are stations marked on the map, which can receive and reflect the signal. The robot does not know where the maze is, but it can send a signal at any time and with some error know the distance to the nearest station. The robot begins to wander the maze, taking each step in a new randomly chosen direction, but his compass also gives some unsystematic error. At each step, the robot determines the distance to the nearest station. The goal is to find out the coordinates of the robot in the maze in the frame of reference entered on the map.

II. PROBLEM STATEMENT

The problem of robot positioning is considered. Let the robot turn on in the dark maze. It has a maze map and a compass. In the labyrinth at some points there are stations marked on the map, which can receive and reflect the signal. The robot does not know where the maze is, but it can send a signal at any time and with some error know the distance to the nearest station. The robot begins to wander the maze, taking each step in a new randomly chosen direction, but his compass also gives some unsystematic error. At each step, the robot determines the distance to the nearest station. The ultimate goal is to find out the coordinates of the robot in the maze in the frame of reference entered on the map [1], [2].

The purpose of the article – solving the following problems: to consider some known approaches to solving problems of linear and nonlinear filtering of statistical / experimental data, which provide the calculation of optimal estimates of the state of the studied objects; perform a detailed analysis of the method of granular Bayesian filtration [3]; give an example of the application of the method of granular filtration and the creation of a decision support system to solve problems of the above type.

We translate the above problem into a model in the state space. The unknown state of the robot, which must be evaluated by granular filtration, is a pair of its coordinates on k step $(x(k), y(k))$. Measured variable $z(k)$ is the distance to the nearest station on the current step. We have such a system of equations:

$$\begin{pmatrix} x(k) \\ y(k) \end{pmatrix} = \begin{pmatrix} x(k-1) \\ y(k-1) \end{pmatrix} + L \cdot \begin{pmatrix} \cos(\theta(k-1)) \\ \sin(\theta(k-1)) \end{pmatrix},$$

$$z(k) = \left\| \begin{pmatrix} x(k) \\ y(k) \end{pmatrix} - \begin{pmatrix} x^* \\ y^* \end{pmatrix} \right\| + \nu(k),$$

where L is the robot step length; $\theta(k) \sim U(\theta^0(k) - \Delta/2,\ \theta^0(k) + \Delta/2)$ is the angle of rotation of the robot in radians on k step. It is evenly distributed, taking into account the error of the compass, in the interval with the center $\theta^0(k)$ – randomly selected for this step the value of the angle of rotation, based on the readings of the compass $\theta(k) \in [0; 2\pi]$; (x^*, y^*) is the coordinate of the station closest to the robot; $\nu(k) \sim N(0, \sigma^2)$ is the error in measuring the distance to the nearest station.

Application of granular filters. To use granular filters, we need distributions $p(x(k), y(k) \,|\, x(k-1), y(k-1))$, $p(z(k) \,|\, x(k), y(k))$.

Obviously that

$$p(z(k) \,|\, x(k), y(k)) = \left| N\left(\left\| \begin{pmatrix} x(k) \\ y(k) \end{pmatrix} - \begin{pmatrix} x^* \\ y^* \end{pmatrix} \right\|,\ \sigma^2 \right) \right|. \quad (3)$$

Consider the distribution $p(x(k), y(k) \,|\, x(k-1), y(k-1))$. For geometric reasons (Fig. 1), if the angle of rotation of the robot is evenly distributed on the segment [3], the coordinate $(x(k), y(k))$ after the step will belong to the corresponding arc with the center at the point $(x(k-1), y(k-1))$ and radius L.

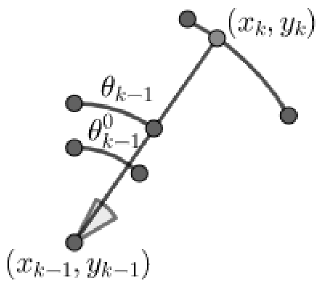

Fig. 1. Robot kinematic ratios

With $(x(k), y(k))$ has a uniform distribution on the arc:

$$p(x(k), y(k) \,|\, x(k-1), y(k-1)) = \begin{cases} \dfrac{1}{2\pi L}, & (x(k), y(k)) \in \text{arc}, \\ 0\ , & \text{otherwise}. \end{cases} \quad (4)$$

State generation $(x(k), y(k))$ from the distribution $p(x(k), y(k) \,|\, x(k-1), y(k-1))$ can be performed directly, namely to generate the implementation of a random variable $\theta(k-1)$, which has a uniform distribution $U(\theta^0(k-1) - \Delta/2,\ \theta^0(k-1) + \Delta/2)$, and calculate $(x(k), y(k))$ from the equation (1).

Since there is no preliminary information on the position of the robot, the initial coordinate $(x(1), y(1))$ is evenly distributed over the obstacle-free area of the maze.

The compass robot has an error, the distribution density of which is given as follows

$$\varphi(\beta) = \frac{e^{-\frac{\tan(\beta/2)^2}{s^2}}}{\sqrt{\pi}\cos(\beta/2)^2 s}, \tag{5}$$

s is the deviation parameter. The smaller s, the smaller the deviation from the direction of motion. Angle $\beta \in (-\pi; +\pi)$.

In this problem, granules $\{x^i(k)\}_{i=1}^{N_S}$ essentially correspond to the hypotheses about the coordinate of the robot. The task is to find at each step the distribution of probabilities over all possible positions of the robot on the map.

In the given program for simulation of the set task there is a granular filtering for the purpose of definition of a condition of work by the chosen method. The screening significance filter (SIR), the auxiliary screening filter (APF), and the regularized granular filter (RPF) described above are available. The basic algorithm of sequential sampling by significance (SIS) in its pure form is not used due to the problem of degeneracy of weights [2]. The methods are implemented in accordance with the above pseudocode with the following clarifications:

- when calculating the distribution $p\big(z(k)\,|\,x(k), y(k)\big)$ according to the formula for granules, the coordinates of which $(x(k), y(k))$ are outside the maze, the value obtained is penalized – multiplied by an empirical factor of 0.5. This reduces the weight of those granules, which obviously do not correspond to the exact position of the robot;
- in APF filter as $\mu^i(k)$ used implementation of the transitional distribution of the state of the robot: $\mu^i(k) \sim p\big(x(k), y(k)\,|\,x^i(k-1), y^i(k-1)\big)$. Then the distribution $p\big(z(k)\,|\,\mu^i(k)\big)$ also has the form like (4);
- in RPF as the proposed distribution $q\big(x(k), y(k)\,|\,x^i(k-1), y^i(k-1) z(k)\big)$ used a priori $p\big(x(k), y(k)\,|\,x^i(k-1), y^i(k-1)\big)$;
- in RPF the Gaussian kernel in two-dimensional space is used as a statistical kernel as it is convenient for it to generate implementations ε.

The RPF threshold N_T empirically chosen equal $0.2 \cdot N_S$ (the coefficient can be changed as a constant in the program code).

III. Program Description

After running the program to simulate the task, a maze field is drawn (Fig. 2) in accordance with the specified structure. White background means free space, black – walls, lots of the dots on the corners of some squares with walls – stations (Fig. 2).

The position and direction of movement of the robot reflects the turtle. The robot changes the direction of movement if it crashes into an obstacle, goes beyond the maze or moves in one direction for too long (10 steps).

The arrows show the current position and direction of movement of the granules.

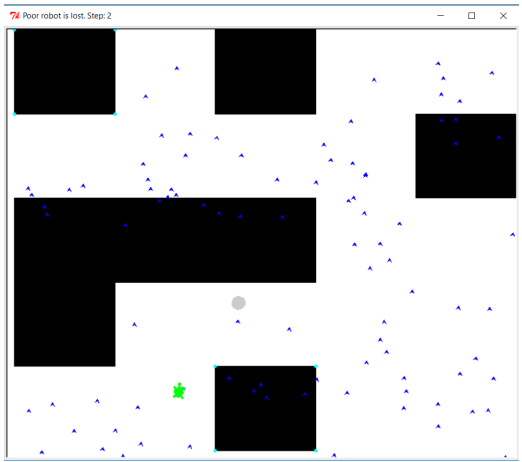

Fig. 2. The field of the maze

The circle indicates the current mathematical expectation of the position of the granules, which is an estimate of the position of the robot. It changes color to green when 95% of the granules are at a distance of no more than 1 from the mathematical expectation.

The current step number is displayed in the title bar of the window.

As a result of the implementation of a given method of granular filtration (Fig. 3) in the case of its convergence, the assessment of the position of the robot from a certain step becomes close to its true position, most of the granules accumulate around it.

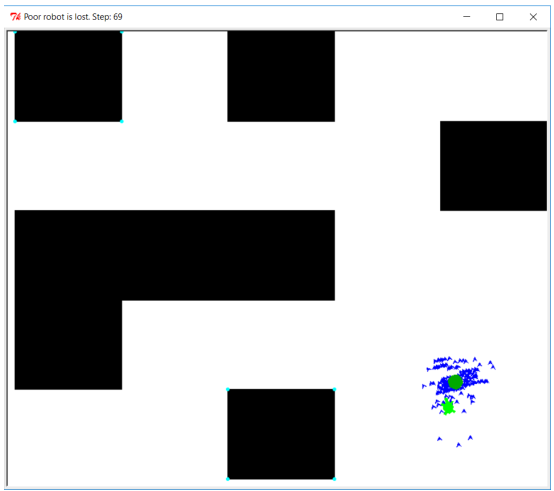

Fig. 3. Implementation of the method of granular filtration

The following files are provided for the work:

- main.py;
- draw.py;
- particle_filter.py.

The speed of the robot (set equal to 0.2) and the number of steps, after which the direction of movement is guaranteed to change, are set as constants in particle_filter.py, they can be changed if desired.

Requirements for the program. The simulation program is created in the Python programming language. Therefore for its work Python 3 or Python 2.7 and such libraries on which the program code depends are necessary: `numpy, random, math, turtle, json, time`.

IV. RESEARCH EXECUTION

1) Run the main.py file and look at the example.

2) Create a new file or modify main.py. Import the following required classes and functions from the provided modules:

```
from particle_filter import Robot, run_model from draw import Maze
```

3) Specify in the code or organize the input from the file of your own maze map in the form of a two-dimensional rectangular structure – a list of lists, tuples (tuple) tuples or something. The size of the maze is arbitrary, for example:

```
maze_map = ( ( 2, 0, 1, 0, 0 ),
             ( 0, 0, 0, 0, 1 ),
             ( 1, 1, 1, 0, 0 ),
             ( 1, 0, 0, 0, 0 ),
             ( 0, 0, 2, 0, 1 ))
```

The following notations have been entered:

0 – empty square;

1 – a square with a wall;

2 – a square with a wall, 4 corners of which are stations.

4) Create a Maze object by specifying a maze map:

```
world = Maze(maze_map)
```

5) Select the parameters of random variables σ from the range $[0.2; 0.8]$ and Δ from the range $[0.05; 0.6]$:

```
sigma = 0.3
delta = 0.5
```

6) Choose a random initial free position for the robot:

```
robot_position = world.random_free_place()
```

7) Create an object of class Robot, setting the parameters of random variables in its model and the initial position:

```
robot = Robot(sigma, delta, robot_position)
```

8) Set the number of granules N_s (depending on the size of the maze) and the number of evaluation steps (preferably at least 200):

```
particle_count = 1500
steps = 100
```

9) Run the model to run with the required parameters. This run will be a test run. The random initial coordinates of the robot and the granules initialized in it, as well as two sequences of random angles (derived from the compass and the real ones, taking into account the error), which determine the direction of the robot, will be saved in an json file. three granular filtration algorithms under the same initial conditions and the same behavior of the object under study. SIRParticleFilter is used by default in this run.

Parameter value *save_parameters = True* will create a file "model_parameters.json" after the end of the model:

```
run_model(robot, world, sigma, delta,
particle_count=particle_count, steps=steps,
save_parameters=True)
```

The created file "model_parameters.json" has the following structure:

```
{
 "init_robot_pos": [
     50,
     50
 ],
 "init_particles_pos": [
     [
         20,
         20
     ],
     [
         30,
         30
     ],…
 ],
 "robot_actual_angles": [
     1.1,
     1.4,
     0.35,…
 ],
 "robot_compass_angles": [
     1.2,
     1.2,
     0.3,…
 ]
}
```

10) Organize reading of json-file "model_parameters.json" with initial parameters and parameters of object behavior. It is suggested to use the function json.load of the library json.

11) Create an object of class Robot, additionally specifying its initial position and list of angles:

```
robot = Robot(sigma, delta, init_robot_pos,
actual_angles=robot_actual_angles,
compass_angles=robot_compass_angles)
```

12) Run the execution model for three granular filtering algorithms: "SIRParticleFilter", "AuxiliaryParticleFilter", RegularizedParticleFilter". Since the initial positions of the granules are specified, as well as a list of angles for the robot, it is not necessary to specify the number of granules and steps. The filtering algorithm is specified by the *filtering_algorithm* parameter. Example:

```
result = run_model(robot, world, sigma,
delta,
init_particles_pos=init_particles_pos,
filtering_algorithm="SIRParticleFilter")
```

The result returned by the *run_model* function is a list of view elements: ((3.5, 4.75), (2.1, 1.7)), where the first pair of numbers is the true coordinate of the robot at the corresponding step, and the second pair is the mathematical expectation of the coordinate of the robot for the calculated a posteriori distribution at this step.

13) Plot graphs of change in time of distance from the real coordinate of the object to its estimation by mathematical expectation for each of three algorithms of a granular filtration.

14) If desired, to investigate the influence of parameters (σ, Δ, the number of granules N_s, the size of the maze, the number of stations, the threshold value N_T in RPF) on the accuracy of the assessment.

V. CONCLUSIONS

Random perturbations of states of dynamic systems negatively affect the quality of state estimation, so this task requires the attention of researchers working to reduce the influence of random perturbations of states on the values (estimates) of variables at the output of systems. Noises (errors) of measurements and perturbations of states are taken into account explicitly by means of mathematical models of dynamic systems in space of states which have gained wide application especially at the decision of problems of synthesis of control systems.

In time series modeling problems in the state space, the basic concept is the state vector, which contains all the information necessary to describe the observed system in a specific problem statement. The measurement vector represents noisy observations associated with the state vector. It may have a smaller dimension than the state vector due to the presence of non-measurable components.

When using probabilistic methods of data analysis to form a probabilistic conclusion about the current state of a dynamic system, it is necessary to build at least two models. First, a model that describes the change in the state of the system over time (model of the dynamics of the system or its state variables); second, a model that links the noisy measurements of the components of the state vector with the processes of existing errors (measurement model). Such models in the space of states should be available for research and practical application in probabilistic form [3], [4].

The task of linear and nonlinear filtering is to form (calculate) a probabilistic conclusion about the state of the system, based on available measurements. Within the Bayesian approach to data analysis, this is done by calculating or approximating the a posteriori distribution of the state vector, provided that all available at the time of calculation measurements and estimates of non-measurable components. Since the function of distribution of probabilities of measurements contains practically all available statistical information concerning the investigated object, its estimation is rather full solution of a problem of an estimation of a condition, forecasting of its further development and support of decision-making [5].

REFERENCES

[1] C. K. Chui and G. Chen, *Kalman Filtering with Real-Time Applications*. Berlin: Springer, 2009, 239 p.

[2] S. Haykin, *Adaptive Filtering Theory*. Upper Saddle River NJ: Prentice Hall, 2007, 920 p.

[3] S. J. Press, *Subjective and Objective Bayesian Statistics*. Hoboken, NJ: John Wiley & Sons, Inc., 2003, 558 p. https://doi.org/10.1002/9780470317105

[4] Dan Liu, Zidong Wang, Yurong Liua, and Fuad E. Alsaadi, "Recursive filtering for stochastic parameter systems with measurement quantizations and packet disorders," *Applied Mathematics and Computation*, Elsevier, vol. 398, 2021. https://doi.org/10.1016/j.amc.2021.125960

[5] A. Pole, M. West, and J. Harrison, *Applied Bayesian Forecasting and Time Series Analysis*, Boca Raton, FL: Chapman & Hall/CRC, 2000, 410 p.

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Bidyuk Petro. ORCID 0000-0002-7421-3565. Doctor of Engineering Science. Professor.
Department of Mathematical Methods of Systems Analysis, National Technical University of Ukraine "Igor Sikorsky Kyiv Polytechnic Institute," Kyiv, Ukraine.
Education: National technical university of Ukraine "Kyiv Polytechnic Institute", (1972).

Research area: mathematical modeling of nonstationary nonlinear processes in different fields, methods of statistical data analysis, adaptive forecasting, automatic control of technological processes and technical systems.
Publications: about 700 scientific papers.
E-mail: pbidyuke_00@ukr.net

Manuilenko Roman. Candidate of Engineering Science. Scientific Employee.
Systems Control Theory Department Institute of Applied Mathematics and Mechanics, National Academy of sciences, Slovyansk, Ukraine.
Education: Donetsk National University, Donetsk, Ukraine, (1994).
Research area: calculation of coordinates of radio emission sources, differential equations, linear algebra and analytical geometry.
Publications: more than 10 scientific papers.
E-mail: ronma2016@gmail.com

Pantyeyev Roman. ORCID 0000-0003-4707-4608. Candidate of Engineering Science. Senior Lecturer.
Aviation Computer-Integrated Systems Department, Faculty for Aeronavigation, Electronics and Telecommunication, National Aviation University, Kyiv, Ukraine.
Education: Donetsk National Technical University, Donetsk, Ukraine, (2001).
Research area: Information Systems, Control Systems Design, Identification of Complex Systems, Mathematical Modeling.
Publications: more than 20 scientific papers.
E-mail: romanpanteevmail@gmail.com

П. І. Бідюк, Р. І. Мануйленко, Р. Л. Пантєєв. Фільтруючі алгоритми визначення координат об'єкта у системах підтримки прийняття рішень

Методи оцінювання параметрів і станів динамічних систем – актуальна задача, результати розв'язання якої знаходять своє застосування у різних галузях діяльності, включаючи дослідження процесів у технічних системах, космологічних та фізичних дослідженнях, медичних діагностичних системах, економіці, фінансах, біотехнологіях, екології та інших. Незважаючи на значні наукові і практичні досягнення у цьому напрямі, дослідники багатьох країн світу продовжують пошуки нових методів оцінювання параметрів і станів досліджуваних об'єктів та удосконалення існуючих. Прикладом таких методів є цифрова та оптимальна фільтрація, які знайшли широке застосування у технічних системах ще у середині минулого століття, зокрема, у обробці фінансово-економічних даних, фізичних експериментах та інших інформаційних технологіях самого різного призначення. Розглядається модель та алгоритми гранулярної фільтрації на практичному прикладі – варіанті задачі глобальної локалізації мобільного робота (global localization for mobile robots) або задачі про викраденого робота (hijacked robot problem). В загальному варіанті вона полягає у визначенні положення робота за даними з сенсора. Ця задача була в цілому розв'язана рядом імовірнісних методів в кінці 90-х-початку 2000-х років. Задача є важливою і знаходить застосування у мобільній робототехніці та промисловості. Схожими за суттю є задачі позиціонування підводних човнів, літальних апаратів, автомобілів та інших рухомих об'єктів.
Ключові слова: оцінювання параметрів; оцінювання станів; динамічна система; гранулярний фільтр; цифрова фільтрація; оптимальна фільтрація; несистематична похибка; позиціонування робота; система підтримки прийняття рішень.

Бідюк Петро Іванович. ORCID 0000-0002-7421-3565. Доктор технічних наук. Професор.
Кафедра математичних методів системного аналізу, Національний технічний університет України «Київський політехнічний інститут ім. Ігоря Сікорського», Київ, Україна.
Освіта: Національний технічний університет України «Київський політехнічний інститут», (1972).
Напрямок наукової діяльності: математичне моделювання нестаціонарних нелінійних процесів у різних галузях, методи статистичного аналізу даних, адаптивне прогнозування, автоматичне управління технологічними процесами і технічними системами.
Кількість публікацій: близько 700 наукових робіт.
E-mail: pbidyuke_00@ukr.net

Мануйленко Роман Іванович. Кандидат технічних наук. Науковий співробітник.
Відділ теорії керуючих систем, Інститут прикладної математики та механіки Національної академії наук України, Слов'янськ, Україна.
Освіта: Донецький національний університет, Донецьк, Україна, (1994).
Напрямок наукової діяльності: розрахунок координат джерел радіовипромінювання, диференціальні рівняння, лінійна алгебра і аналітична геометрія.
Кількість публікацій: понад 10 наукових робіт.
E-mail: ronma2016@gmail.com

Пантєєв Роман Леонідович. ORCID 0000-0003-4707-4608 Кандидат технічних наук. Старший викладач.
Кафедра авіаційних комп'ютерно-інтегрованих комплексів, Факультет аеронавігації, електроніки та телекомунікацій, Національний авіаційний університет, Київ, Україна.
Освіта: Донецький національний технічний університет, Донецьк, Україна, (2001).
Напрямок наукової діяльності: інформаційні системи, проектування систем управління, ідентифікація складних систем, математичне моделювання.
Публікації: понад 20 наукових робіт.
E-mail: romanpanteevmail@gmail.com

П. И. Бидюк, Р. И. Мануйленко, Р. Л. Пантеев. Фильтрующие алгоритмы определения координат объекта в системах поддержки принятия решений

Методы оценки параметров и состояний динамических систем – актуальная задача, результаты решения которой находят свое применение в различных областях деятельности, включая исследования процессов в технических системах, космологических и физических исследованиях, медицинских диагностических системах, экономике, финансах, биотехнологиях, экологии и других. Несмотря на значительные научные и практические достижения в этом направлении, исследователи многих стран мира продолжают поиски новых методов оценки параметров и состояний исследуемых объектов и усовершенствование существующих. Примером таких методов является цифровая и оптимальная фильтрация, которые нашли широкое применение в технических системах еще в середине прошлого века, в частности, в обработке финансово-экономических данных, физических экспериментах и других информационных технологиях самого разного назначения. Рассматривается модель и алгоритмы гранулярной фильтрации на практическом примере – варианте задачи глобальной локализации мобильного робота (global localization for mobile robots) или задачи о похищенном работа (hijacked robot problem). В общем варианте она состоит в определении положения работа по данным из сенсора. Эта задача была в целом решена рядом вероятностных методов в конце 90-х-начале 2000-х годов. Задача является важной и находит применение в мобильной робототехнике и промышленности. Схожими по сути задачи позиционирования подводных лодок, летательных аппаратов, автомобилей и других движущихся объектов.

Ключевые слова: оценивание параметров; оценивание состояний; динамическая система; гранулярный фильтр; цифровая фильтрация; оптимальная фильтрация; несистематическая погрешность; позиционирование работа; система поддержки принятия решений.

Бидюк Петр Иванович. ORCID 0000-0002-7421-3565. Доктор технических наук. Профессор.
Кафедра математических методов системного анализа, Институт прикладного системного анализа, Национальный технический университет Украины «Киевский политехнический институт им. Игоря Сикорского», Киев, Украина.
Образование: Национальный технический университет Украины «Киевский политехнический институт», (1972).
Направление научной деятельности: математическое моделирование нестационарных нелинейных процессов в различных областях, методы статистического анализа данных, адаптивное прогнозирование, автоматическое управление технологическими процессами и техническими системами.
Количество публикаций: около 700 научных работ.

Мануйленко Роман Иванович. Кандидат технических наук. Научный сотрудник.
Отдел теории управляющих систем, Институт прикладной математики и механики Национальной академии наук Украины, Славянск, Украина.
Образование: Донецкий национальный университет, Донецк, Украина, (1994).
Направление научной деятельности: расчет координат источников радиоизлучения, дифференциальные уравнения, линейная алгебра и аналитическая геометрия.
Количество публикаций: более 10 научных работ.
E-mail: ronma2016@gmail.com

Пантеев Роман Леонидович. ORCID 0000-0003-4707-4608.
Кандидат технических наук. Старший преподаватель.
Кафедра авиационных компьютерно-интегрированных комплексов, Факультет аэронавигации, электроники и телекоммуникаций, Национальный авиационный университет, Киев, Украина.
Образование: Донецкий национальный технический университет, Донецк, Украина, (2001).
Направление научной деятельности: информационные системы, проектирование систем управления, идентификация сложных систем, математическое моделирование.
Публикации: более 20 научных работ.
E-mail: romanpanteevmail@gmail.com