ELECTRONIC INTELLIGENT AGENTS FOR CONTROL OF MECHATRONICS SYSTEM

ELEKTRONISKIE INTELEKTUĀLIE AĢENTI MEHATRONIKAS SISTĒMAS VADĪBAI

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Introduction

The paper is based on author’s previous scientific work researching the intelligent agent systems [10] and its’ application in mechatronic systems. Intelligent agents are computer modules, which work in global network and use methods of the artificial intelligence. Intelligent agents have possibility to negotiate with each other and to co-operate their work to get better decision.

It was offered by several researchers. Very prevalent subject for usage of artificial intelligence is a fault analysis. The closest work to our subject is development of a new intelligent control and diagnostic system for Tallinn trams [9]. System operation modes and their diagnostic possibilities and methods were studied. The work presents and tests the possibility of such system usage. It provides a structure of a tram board controller for diagnostics, an expert system for coordination, as well as usage of wireless GSM network for communication. The expert system is possible to use complicated diagnostic methods, like fuzzy logics, neural networks and hybrid methods of fault analysis and anticipation.

Although, the usage of AI is provided in a big quantity of works, the agent systems are not so popular for use in electrotechnics and electrotechnology. Usually agents are represented as a physical unit only. But in some cases intelligent agent systems are supposed. As an example, Hungarian researchers in [7] offer the solution method of tracking control problem in very limited and closed Intelligence Space based on agents and neural networks.

Problem Formulation

Nowadays a number of transport units in the cities increases rapidly, i.e. transport flow is growing. Nevertheless, traffic lights regulate this flow, each traffic lights works independently from others. Therefore, the transport flow is uncontrollable.

If the participants of this flow are not only private cars, but also public electric transport, such situation yields losses of electrical energy, because of frequent braking and acceleration on crossroads between passengers stops.

There are two contrary criterions of optimality for public transport. From the one side, electric transport uses electric energy, so the criterion is the energy consumption that has to be minimized. From the other side, public transport has the schedule and must follow it.

There are three main safety levels in transport systems. The first is the safety of mechatronics system of a train. That means, an intelligent diagnostic system for engine states is needed to separate dangerous situations by critical testimonies from sensors from the regular states of the system.

The second level is the safe control of mechatronics system in an train. One of the primary tasks is an intelligent speed control of a train, using multi-criterial decision making [3,11], taking in account weather factors, state of the way and schedule.
The third safety level includes an intelligent control of the whole transport system. That is why the solution of coordination task between all trains in the system is necessary.

Method of Solution

Author propose to use intelligent agent system for all three safety levels.
Intelligent agents for diagnostics system of a train engines [2], based on neural network and clustering, give possibility to detect and warn about changes in the engine, detect the problem immediately, and to fix it in some cases without human intervention.
Methodologies used for mechatronics system control in the research are bond graphing, expert systems and negotiations.
The research proposes the algorithm of intelligent speed control [6] and the solution for coordination task between intelligent trains with a purpose to prevent accidents using the algorithm of negotiation for intelligent agents [4].
Mechatronics systems are power and flow based systems. That's why, the structure of intelligent control of mechatronics system by electronic device can be presented using Bond graphing elements. In details it is presented in Figure 1. It describes an electric vehicle motion control process, where the main object to control is a traction engine. Figure 1 shows power flows and causalities in control of electric vehicle mechatronics system. Flows in intelligent agent system f1, f2 and flows between sensors, microcomputer and intelligent agent devices f0, f3, f4 are considered as activators only with zero energy flow.

- f_0 – vehicle speed - v; vehicle position – x, y ; signals of action (accelerating, braking)
- f_1 – data about parameters of vehicle
- f_2 - signals of action;
- f_3 – torque – T; rotation speed- ω.
- f_4 – activation signal

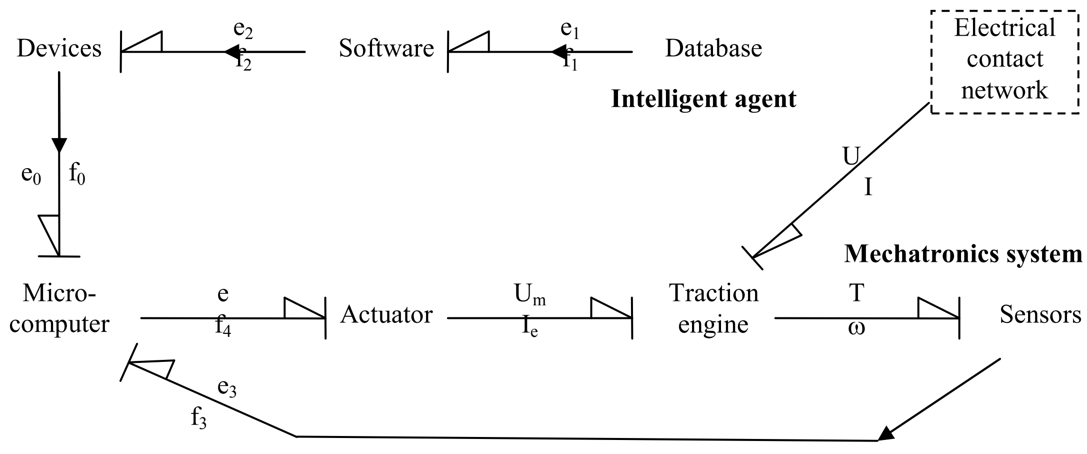

Figure 1. Power and activation flows in electric vehicle mechatronics system control

The research proposes the solution for coordination task between intelligent electric transport units and intelligent electric traffic control units with a purpose of electric energy saving.
The model of electric transport system is defined and the algorithm for electric vehicle motion control with negotiations between electric devices using intelligent agent approach is presented.
The intelligent superagent is responsible for negotiation process between intelligent agents. The superagent organizes group decision making process. Other agents are responsible only for their own objects, share operational information and accept or do not accept decisions and negotiation according to possible concessions. All conflicts in intelligent electric transport system are solved through negotiation process. Superagent plays a role of the arbitration judge, which nominates what participants have to do proceeding from results of negotiation.

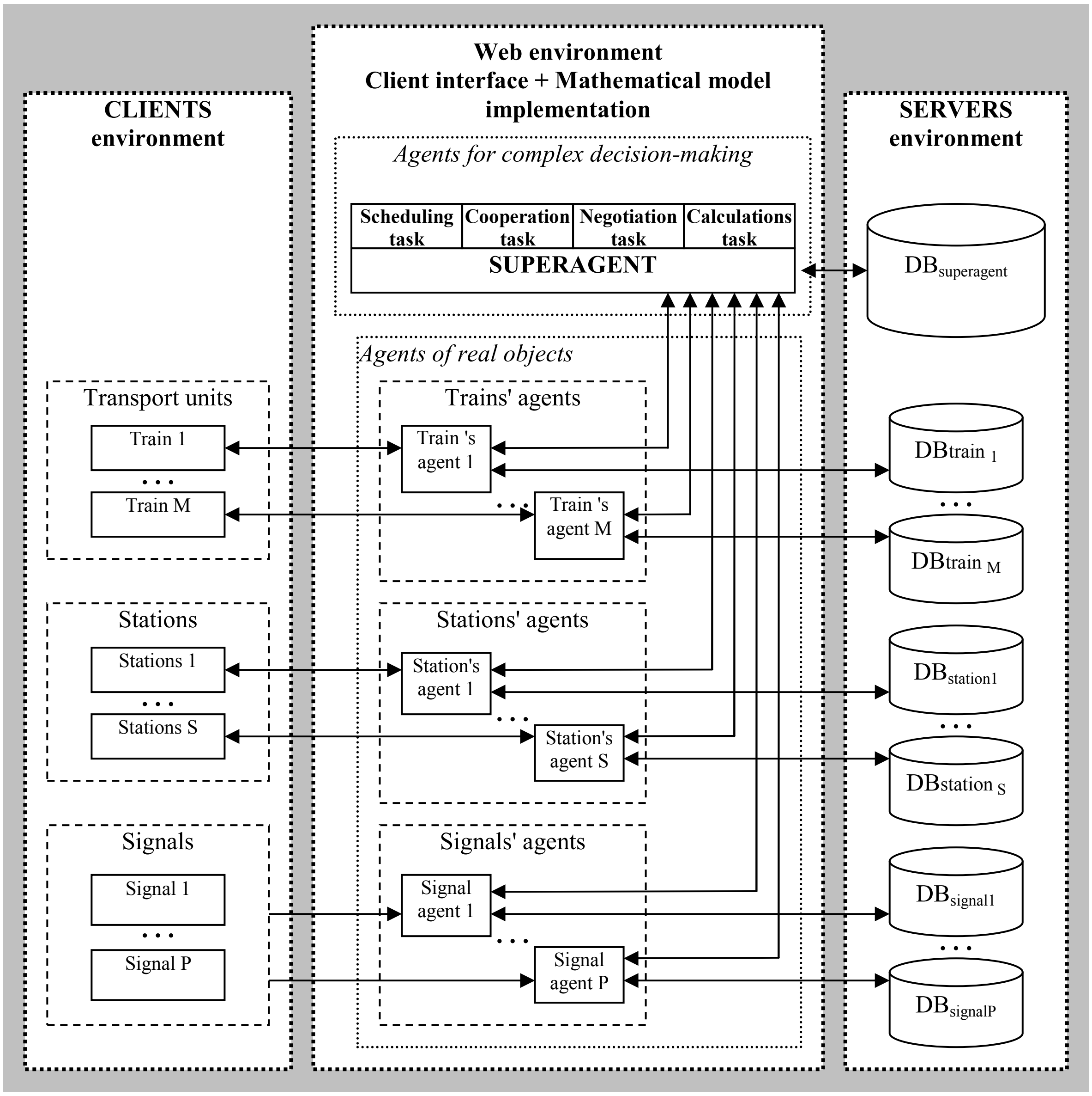

Figure 2. Interaction of IMAS in Web environment with Client-Server environment of electric transport system.

The scheduling task is represented as a cooperative, non-coalition game, where all agents and each is responsible only for its own object. The result of negotiation algorithm is the schedule of operational instructions for all participants of negotiation.

Neural Networks

Clustering analysis is based on artificial neural network model. Neural network mathematical model is based on perceptron structure. Each neuron is a perceptron with input data set, weight for each input data, activation function and output, which usually has binary value. Neural network consists of several layers. Each layer may have definite or indefinite number of neurons. Neural networks give possibility to analyse an object by input parameter set and to detect predefined class of the object on the output. That means, neural network should be trained to detect classes and classes are predefined.

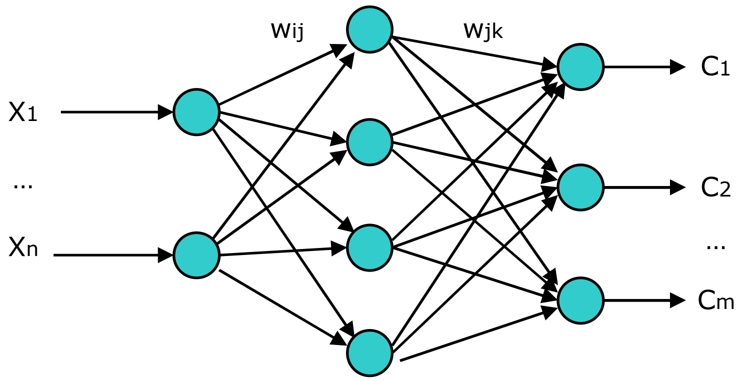

Figure 3. Neural Network structure

Clustering Analysis

Clustering is one of adaptation methods. It gives self-training possibilities to the intelligent agents and allows to classify unorganized input data. This way, clustering give possibility to create new neurons on the output layer of the neural network. Clustering analysis is used when output classes are not predefined. Mathematical model for clustering consists of following elements: set of input objects; set of attribute vectors for each object; dynamic set of clusters with variable size – at the beginning of analysis it is empty; dynamic set of prototype vectors for each cluster – attribute vector, which defines the class; set of cluster members for each cluster; set of sum vectors for each member – defines the correspondence of each member to prototype vector of the cluster; parameter of attentiveness – affects the precision of clustering analysis.

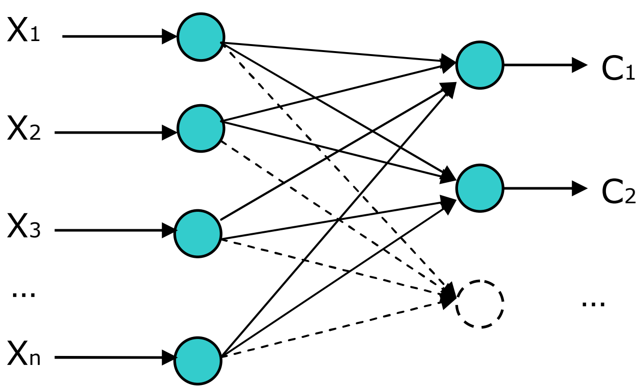

Figure 4. Neural Network creation by clustering

Mathematical Model

Model for Genetic Algorithm

Author propose to use electronic intelligent agent system for decision-making to control traffic lights corresponding to the transport flow. The target is to minimize of total electric energy usage by electric transport and average idle time for all transport flow participants using genetic algorithm for intelligent agents of traffic lights.

The purpose of this paper is to define fitness function for genetic algorithm. Genetic algorithm is realised for intelligent superagent to optimize green and red light time. Fitness function should include idle time calculation for all transport participants in traffic jam and electric energy consumption.

Input data:

Crossroad parameters:

- set of crossroads - K
- number of transport units – n_{jk}, where j – direction, k - crossroad;
- flow rate of crossroad (number of lines) – l;
- average speed of moving car (without stop) – v;

Parameter for i^{th} transport unit

- driver's average reaction time – r_i;
- acceleration time for one transport unit – a_i;
- length of a car - c_i;
- distance between cars in traffic jam - d_i;
- position in traffic jam - p_i;

Variables:

- green light time – x_k;
- red light time – y_k;

where k – crossroad.

Target functions:

- Average waiting time – $T = \Sigma t_i / \Sigma n \rightarrow \min$
- Average flow speed - $V = \Sigma v_i / \Sigma n \rightarrow \max$
- Electric energy - $E = \Sigma e_i \rightarrow \min$

Auxiliary functions:

- time of moving from position to the crossroad –

$$t_i = \frac{(p_i - 1)\cdot(c_i + d_i)}{v} + (r_i + a_i)\cdot p_i \tag{1}$$

- flow rate of traffic light:

$$f = \frac{(v \cdot x - c_i - d_i)}{(c_i + d_i + (r_i + a_i) \cdot v)} \cdot l; \quad f \in \aleph \tag{2}$$

- red light times (green light missing):

$$r = p_i / f; \quad f \in \aleph \tag{3}$$

- red light waiting time:

$$t_{ir} = f \cdot y; \quad f \in \aleph \tag{4}$$

- position before passing crossroad:

$$p_i^{'} = p_i - f \cdot r; \quad f \in \aleph \tag{5}$$

Fitness function for optimization:

$$T = \left(\sum_{i=0}^{n} t_i(x, y) = \frac{(p_i^{'} - 1) \cdot (c_i + d_i)}{v} + (r_i + a_i) \cdot p_i^{'} + t_{ir} + r \cdot x \right) / n \rightarrow \min \tag{6}$$

$$V = \left(\sum_{i=0}^{n} \frac{p_i \cdot (c_i + d_i)}{v} \right) / n \rightarrow \max \tag{7}$$

$$E = \sum_{i=0}^{m} (f_k + 1) \cdot t_{ir} \cdot p_i \rightarrow \min \tag{8}$$

Normalization functions
Let us assume, that maximal values of target functions are:

- T_{max} = 3600 s;
- V_{max} = 50 kmh;
- E_{max} = 1000 kWh.

According to this values normalization is:

$$T' = \frac{T_{\max} - T}{T_{\max}} = \frac{3600 - T}{3600} \tag{9}$$

$$V' = \frac{V}{V_{\max}} = \frac{V}{50} \tag{10}$$

$$E' = \frac{E_{\max} - E}{E_{\max}} = \frac{1000 - E}{1000} \tag{11}$$

Let us assume the priorities for optimization parameters are

- $\alpha_T = 0.3$;
- $\alpha_V = 0.3$;
- $\alpha_E = 0.4$.

Fitness function for optimization:

$$F = \alpha_T T' + \alpha_V V' + \alpha_E E' \rightarrow \max$$

Diagnostic System of Electric Engine

Set of states of an engine – $I^e = \{i_1^e, i_2^e, \ldots\}$

Set of properties of an engine – $X_i^e = \{x_{i1}^e, \ldots, x_{in}^e\}$

Set of clusters of engine states – $C^e = \{c_1^e, c_2^e, \ldots\}$

Engine states,members of cluster $M_c^e = \{m_{c1}^e, m_{c2}^e \ldots\}$

Prototype-vectors of clusters - $P_c^e = \{p_{c1}^e, \ldots, p_{cn}^e\}$

Sum vector of engine state - $S_m^e = P_c^e \cap M_c^e = \{s_{m1}^e, \ldots, s_{mn}^e\}$

Vigilance of agent – ρ^a $(0 < \rho^a \leq 1)$.

Weights: $W = \{w_1, w_2, \ldots, w_n, w_{n+1}\}$

Fitness function: $F = x_1 * w_1 + x_2 * w_2 + \ldots + x_n * w_n + w_{n+1}$

Mechatronics System Parameters

1. net voltage U
2. net current I_k
3. net resistance R_k
4. motor excitation current I_e
5. motor armature current I
6. magnetic flux c_f
7. motor torque constant $c_m = c_f / 6.28$
8. rotation speed n
9. motor voltage U_m
10. duty ratio of pulse regulation g
11. used net energy E_a
12. used vagon energy E_v
13. recuperation probability a
14. recuperation energy E_{rek}

Coordination System for Electric Transport System

1. A set of processors P – stations and points,

   where $P = \{P^1, P^2\}$, $P \in N$, where

Stations: $P^1 = \{p_1^1, p_2^1, ..., p_s^1\} \subset P$

Points: $P^2 = \{p_1^2, p_2^2, ..., p_c^2\} \subset P$

2. A set of jobs *V* – trains, where $V = \{v_1, v_2, ..., vu_m\}$
3. Train's schedule: $\sigma_v : P^1 \to \{t_{v1}, t_{v2}, ..., t_{vs}\} \subset \Re$
4. Stations's schedule: $\sigma_{p^1} : V \to \{t_{p1}, t_{p2}, ..., t_{pm}\} \subset \Re$
5. Additional payments matrix A with criterions r, where $A = \{a_{1,1}, a_{1,2}, \dots, a_{r,n\times t}\}$, $r \in Z$, $n=|P|$, $t=|V|$;
6. A negotiation set B, where $B = \cap\sigma_k \to \varnothing$; Element conflicting objects and time to negotiate.
7. A set of time crossings $C \subset B$
8. A set of directive terms infringements $E \subset B$.

Algorithms for Problem Solution

Clustering Algorithm for Engine Diagnostic [2]

Intelligent diagnostics can be solved by implementing of neural network model and clustering algorithm.

Step 1: The first prototype vector creation from the first property vector – $P_{c1}^e = X_{i1}^e$

Step 2: Cycle. Next object $i \in I$ is checked to be assigned to cluster from *C*.

Step 2.1. Check for vigilance: $|P_c^e \cap X_i^e| / (\beta + |P_c^e|) > |X_i^e| / (\beta + n)$; No – Step 4.

Step 2.2: Compare of with vigilance parameter: $|P_c^e \cap X_i^e| / |X_i^e| < \rho^a$;No - Step 4

Step 2.3. Check for identity: $|P_c^e| = |X_i^e|$? ; No - Step 4

Step 3: Assign current object *i* to cluster members $M_c^e (i = m \in M_c^e)$ .Go to Step 2

Step 4: Create new prototype vector. Go to. Step 2.

Algorithm of Intelligent Speed Control [6]

Optimal energy consumption will be achieved by optimal and safe control of electric vehicle using intelligent devices. The mathematical model for intelligent agents of electric transport system is offered for task solution.

The algorithm of optimal speed control is provided for vehicle's agent. The algorithm includes intelligent speed control procedure and negotiations between intelligent agents.

Step 1. Detect next checkpoint - *chp*

Step 2. Calculate breaking point and breaking time:

brp = chp_dist – breaking_way(vmin → 0)

brt = breaking_time(vmin → 0)

Step 3. Calculating rolling way and rolling time :

rw = rolling_way(v → vmin)

rt = rolling_time (v → vmin)

Step 4. Evaluating the rolling way: *brp = s + rw ?*

Yes – Step 5; No – Step 3

Step 5. If checkpoint type is a point: type[chp]=“X”?
Yes– Step 6; No – Step
Step 6. Start negotiations with point agent;
Step 7. Signal = green ?
Yes – Step 1; No – *acceleration = false*
Step 8. If checkpoint type is station: type[chp]=“S”?
Yes – Step 9 No – *acceleration = false*
Step 9. Start negotiations with station agent;
Step 10. Satisfies directive term $rt + brt \leq t(chp)$?
Yes – *acceleration = false;* No – Step 3

Algorithm of Negotiations between Trains 8
Step 1. Getting input data from all jobs and processors about current situation in a zone;
Step 2. Negotiation Set B creating for all trains coming to the point or station;
Step 3. Crossing time set C calculating;
Step 4. Directive term checking - set E;
Step 5. CONFLICT ?
Yes - New restriction in B, Step 2; No – Step 6;
Step 6. Creating new schedules;
Step 7. Sending acceptation messages to participants;

Computer Experiment

The specific environment is developed by author for the dynamic modelling of intelligent agents for safety improving algorithms. The interface is presented on Fig.5.
The algorithms were checked for different mechatronic system of different public electric transport types.
As an example, a tram system with real parameters and railway system is taken for optimal energy consumption and safety tasks solution.

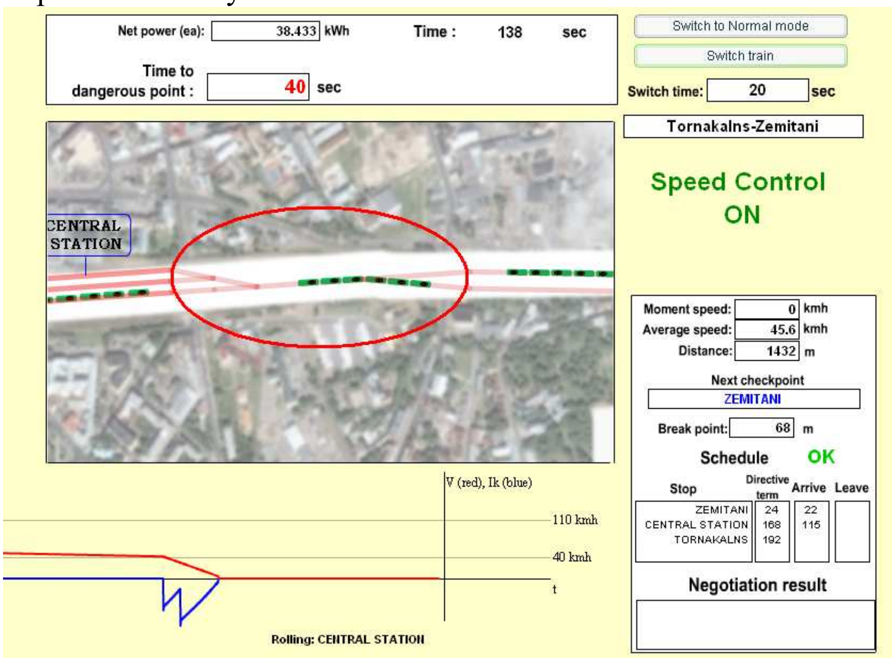

Figure 5. Interface of dynamic model of electric transport

The results of using algorithms of artificial intelligence in public electric transport systems shows the possibility to avoid crashes and detect dangerous points on the way. They advance safety improvement, optimization of energy usage, profit increasing, idle time minimization and coordination.

Conclusions

The results of using algorithms of artificial intelligence in public electric transport systems show the possibility to avoid crashes and detect dangerous points on the way. They advance safety improvement, optimization of energy usage, profit increasing, idle time minimization and coordination. Simulation results prove the efficiency of provided algorithms in mechatronic systems. Usage of algorithms and models allow to reduce charges for energy consumption and to provide more safe service.

The additional value is the possibility of the developed systems to prevent accidents and to avoid different problems by intelligent diagnostic and coordination devices. General algorithm for diagnostics in intelligent agent systems gives possibility to detect the problem of electric vehicle immediately, to fix it in some cases without human intervention or inform all other participants about the problem.

Negotiations in intelligent agent systems give the possibility to coordinate actions of all participants in transport systems and to realize multi-criteria decision-making in control, diagnostic and scheduling for city electric transport.

Intelligent agents system based on the proposed models and algorithms are created using web-technologies, a database and the appropriate programming languages that allow to realize negotiation easy and effectively.

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Gorobecs M. Elektroniskie intelektuālie aģenti mehatronikas sistēmas vadībai.
Pētījuma mērķis ir izstrādāt jaunus matemātiskos modeļus un jaunus algoritmus intelektuālām elektroniskām iekārtām elektriskā transporta mehatronikas sistēmu vadībai. Modeļi un algoritmi bāzēti uz intelektuālo multiaģentu sistēmām.
Pētījuma galvenie mērķi ir elektroenerģijas patēriņa samazināšana un optimāla izmantošana un drošības līmeņa paaugstināšana elektriskā transporta sistēmās.
Iespējamais problēmas risinājums ir intelektuālo aģentu izmantošana. Darbā tiek piedāvāti trīs uzdevumu risinājuma modeļi: mehatronikas sistēmas diagnostikas uzdevums, mehatronikas sistēmas optimālas vadības uzdevums un koordinācijas uzdevums, kas aptver visu elektriskā transporta sistēmu kopumā.
Diagnostikas sistēmai tiek piedāvāts izmantot mākslīgos neironu tīklus un klasterizācijas algoritmu. Optimālas vadības uzdevums tiek risināts ar optimālo elektrotransporta ātruma vadības algoritmu. Koordinācijas uzdevums tiek risināts, izmantojot intelektuālo aģentu sarunu teoriju, sarakstu teoriju un ģenētisko programmēšanu.
Izmantojot šos algoritmus intelektuālo multiaģentu sistēmai, ir iespējams laikus noteikt bīstamas situācijas un bojājumus, nekavējoties brīdināt vai apturēt mehatronikas sistēmu, optimāli izmantot elektrisko enerģiju, izpildot kustību pēc saraksta, un koordinēt visu elektriskā transporta sistēmu kopumā.

Gorobetz M., Electronic intelligent agents for control of a mechatronic system.
The purpose of the research was to develop new mathematical models and algorithms for intelligent electronic devices to control mechatronic systems for electric transport. The models and algorithms are based on intelligent multi-agent systems.
The problems to be solved were energy saving and safety level increasing in the electric transport systems.

Possible solution of the problems is to use intelligent agents. The paper proposes models for solving three tasks: the diagnostics of a mechatronic system, the optimal control of a mechatronics system, and the coordination between all elements of the electric transport system.
To solve the diagnostic task, artificial neural networks and clustering algorithm were recruited. The optimal control task is solved using an optimal speed control algorithm for an electric vehicle, while solution of the coordination task is based on the negotiation theory of intelligent agents, the scheduling theory and the genetic programming.
The proposed algorithms make it possible to detect dangerous situations and defects immediately; to warn or stop the mechatronic system in the case of emergency, to use optimally the electric energy meeting the schedule; and to coordinate the transport system as a whole.

Горобец М., Электронные интеллектуальные агенты для управления мехатронической системой.
Цель исследования – разработать новые математические модели и новые алгоритмы для интеллектуальных электронных устройств для управления мехатронической системой электротранспорта. Модели и алгоритмы основаны на системах интеллектуальных мульти-агентов.
Главные цели исследования – уменьшение расхода электроэнергии и повышение уровня безопасности в системах электротранспорта.
Возможное решение – использование интеллектуальных агентов. В статье предлагаются модели для решения трех задач: задачи диагностики мехатронической системы, задачи оптимального управления мехатронической системой и задача координации между всеми элементами системы электротранспорта.
Для решения задачи диагностики предложено использовать искусственные нейронные сети и алгоритм кластеризации. Задача оптимального управления может быть решена с помощью алгоритма оптимального управления скоростью движения. Задача координации решается с помощью теории переговоров интеллектуальных агентов, теории расписаний и генетического программирования.
Предложенные алгоритмы дают возможность немедленно выявить опасные ситуации и дефекты; предупредить или остановить мехатроническую систему в случае опасности; оптимально использовать электроэнергию, соблюдая при этом расписание; а также координировать всю транспортную систему в целом.