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MODELLING OF OPTIMAL SPEED CONTROL AND ACOUSTIC EMISSION FOR INTELLIGENT ELECTRIC RAILWAY TRANSPORT

OPTIMĀLĀS ĀTRUMA VADĪBAS UN AKUSTISKO EMISIJU MODELĒŠANA INTELEKTUĀLĀ ELEKTRISKĀ DZELZCEĻA TRANSPORTĀ

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Introduction

This work is based on authors' previous research of intelligent transport systems and optimal speed control of electric vehicles as well as electric railway transport. The previous research task was devoted to energy saving and scheduling. The following investigation includes the modelling of acoustics emissions of electric train and usage of optimal speed control algorithm to reduce railway noise.

Noise reduction becomes more actual problem every day, taking in account progressive improvement of high speed railways. By Computation of Railway Noise (CRN) model, which is used to evaluate and calculate noise level, main argument of acoustic level function is speed of a train. Acoustic emission of high speed trains may be dangerous for human health. Even noise level of Latvian railway is higher, than it is set up by EU standards. It reduces comfort level and as a result service level for passengers.

There are different ways how to reduce noise of rolling stock by developing of new electric drives, new shock absorbers, new sound isolation system of cabin and passenger compartments and so on. All previous methods need the development of new technical equipment. Authors proposed to use optimal speed control algorithm for intelligent transport control system, which solves multi-objective optimisation task by noise reduction and energy saving criteria without infringements of the schedule.

Problem Formulation

The purpose of research is to develop new mathematical models and algorithms for intelligent transport system for optimal electric railway speed control to reduce acoustic emissions of the train.

Main goals are

- Development of multi-objective target functions and algorithm for optimal control of electric railway transport by criteria of:
 - minimisation of acoustic emission;
 - minimisation of consumption of electrical energy;
- Research of using of developed procedures in computer modelling of electrical railway transport systems' optimal control.
- Creating of dynamic visual model of electric railway and simulation of proposed speed control algorithm in comparison with existing human control of electric railway.

Mathematical Model

Following mathematical model based on CRN (Calculation of Railway Noise) model of acoustic emission is proposed

The reference SELref at a given speed and at a distance of 25 m from the near-side rail of the track segment taking into account the length of the train and the type of track and track support system. Note that, if the track sleepers are laid on ballast, a correction of -1.5 dBA is applied, except if the railway is a single track or the vehicle is a locomotive on full power.

Unpowered vehicles:

$$SEL_v = 31.2 + 20 \lg v + C_1$$

Locomotives:

$$SEL_v = 112.2 - 10 \lg v + C_1$$

Total for N identical vehicles:

$$SEL_{Ti} = SEL_v + 10 \lg N$$

$$SEL_{ref} = 10 \lg \sum_{i=1}^N 10^{SEL_{Ti}/10} + C_2$$

Corrections to the SELref for distance of the reception point from the track, ground and air absorption, the effect of screening by barriers, and the angle of view at the reception point.

$$C_{dist} = -10 \lg(d'/25) \quad d > 10m$$

$$C_{abs} = 0.2 - 0.008d$$

$$C_{ground} = \begin{cases} -3P_d \lg(d/25) & H < 1m \\ -0.6P_d(6-H) \lg(d/25) & 1m < H < 6m \\ 0 & H > 6m \quad 10m < d < 25m \end{cases} + \begin{cases} -1.5dB \\ 0 \end{cases}$$

Corrections to SELref to take account of reflection effects at the reception point. The most usual is a Facade correction at 1 m, of +2.5 dBA

The SELref at the reception point by applying the corrections determined at stages 3 and 4 to the SELref, and convert the resulting SEL values to values of LAeq taking into account the time period required and the number of trains, N:

$$SEL = \sum SEL_{ref} + \sum C$$

$$LAeq, 6\text{-hour} = SEL - 43.3 + 10 \lg 10N$$

$$LAeq, 18\text{-hour} = SEL - 48.1 + 10 \lg 10N.$$

Stage 6. Combine the LAeq for each segment to obtain the total day and night LAeq for the railway.

$$L_{total} = 10 \lg(\sum 10^{L/10})$$

Stages 1-6 are carried out using a chart-based procedure similar to that detailed in the CRTN. The method allows us to predict the levels of noise for:

- multi-tracks
- freight and passenger trains
- diesel and electric haulage
- maximum speed up to 250 km/h.

Electromechanical Parameters for Train.

- Railway net voltage U^R
- Railway net current I_k^R
- Railway net resistance R_k^R
- Train motor excitation current I_e^t
- Train motor armature current I^t
- Train motor magnetic flux c_f^t
- Train motor torque constant $c_m^t = c_f / 6.28$
- Train motor rotation speed n^t
- Train motor voltage U_m^t
- Duty ratio of pulse regulation g^t

- Used net energy by train E_a^t
- Recuperation probability of train a^t
- Recuperation energy of train E_{rek}^t

Coordination System between Trains

- A set of processors P – stations and points;
where $P = \{P^1, P^2\}$, $P \in N$, where
 - Stations: $P^1 = \{p_1^1, p_2^1, \dots, p_s^1\} \subset P$
 - Points: $P^2 = \{p_1^2, p_2^2, \dots, p_c^2\} \subset P$
- A set of jobs V – trains, where $V = \{v_1, v_2, \dots, v_{u_m}\}$;
- Train's schedule: $\sigma_v : P^1 \rightarrow \{t_{v1}, t_{v2}, \dots, t_{vs}\} \subset \mathfrak{R}$;
- Stations's schedule: $\sigma_{p^1} : V \rightarrow \{t_{p1}, t_{p2}, \dots, t_{pm}\} \subset \mathfrak{R}$;
- Additional payments matrix A with criterions r, where $A = \{a_{1,1}, a_{1,2}, \dots, a_{r,n \times t}\}$, $r \in Z$, $n = |S|$, $t = |U|$;
- A negotiation set B, where $B = \bigcap \sigma_k \rightarrow \emptyset$;
Element conflicting objects and time to negotiate.
- A set of time crossings $C \subset B$;
- A set of directive terms infringements $E \subset B$.

Algorithms for Problem Solution

Authors have proposed speed control algorithm for reduction of acoustic emission of electric railway
Algorithm consists of the following steps:

- Step 1. Detect next checkpoint - *chp*
- Step 2. Calculate breaking point and breaking time:
 $brp = chp_dist - breaking_way(vmin \rightarrow 0)$
 $brt = breaking_time(vmin \rightarrow 0)$
- Step 3. Calculating rolling way and rolling time :
 $rw = rolling_way(v \rightarrow vmin)$
 $rt = rolling_time(v \rightarrow vmin)$
- 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 3
- 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

Proposed algorithm takes in account also optimal energy consumption that is achieved by optimal and safe control of electric vehicle using intelligent devices. The algorithm of optimal speed control is provided for train's agent. The algorithm includes intelligent speed control procedure and negotiations between intelligent agents.

Computer Experiment

The specific environment is developed by authors for the dynamic modelling of intelligent railway system for noise and energy saving control. The interface is presented on Fig. 1.

The algorithms were checked for different mechatronic system of different public electric transport types. As an example, a railway system with real parameters is taken for optimal energy consumption.

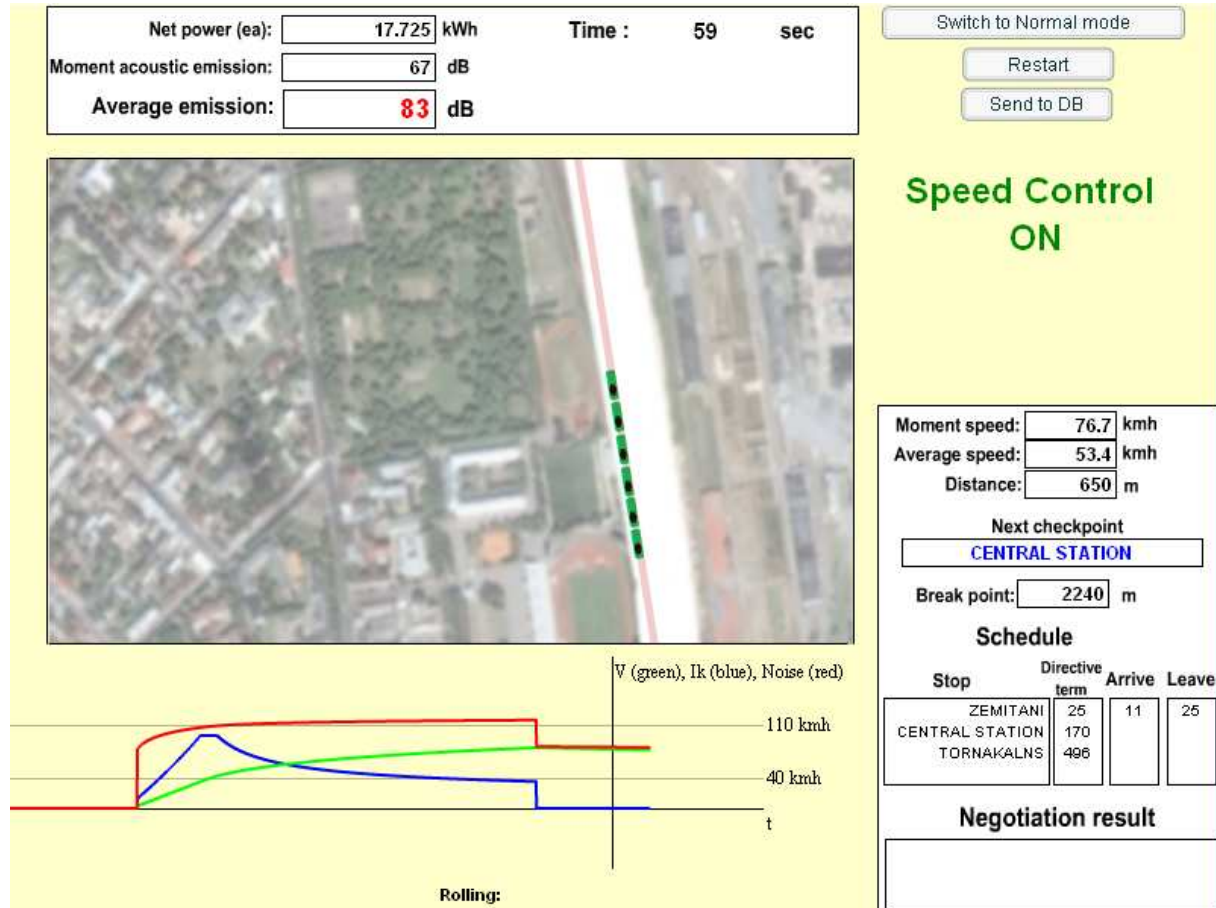


Fig. 1. Interface of dynamic model of electric transport

The graphics on the figure presents noise level, which is increasing during acceleration. Also electric energy is consumed when accelerating. This way optimal speed control gives the results presented in table 1.

Table 1

Comparison of algorithms			
	Schedule	Electric energy, kWh	Average acoustic emission, dB
Existing control	OK	36,52	74
Intelligent speed control	OK	27,48	67
Comparison		24%	9%

The results show the possibility to reduce consumption of electrical energy by 24% and reduction of acoustic emission by 9%

Conclusions

Proposed model and algorithm may be used for intelligent transport system to control speed of railway transport, taking in account noise, electric energy and schedule criteria. Results of modelling of these procedures show efficiency of proposed methods in railway task solutions.

Developed procedures give possibility to realize algorithm of optimal speed control for modelling of intelligent agents to reduce consumption of electrical energy and acoustic emissions.

The result of computer modelling does not include costs for installation of necessary devices. Realistic value should be not less than 12% of reduction of electric energy consumption and not less than 5% for acoustic emission.

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Gorobecs M., Ļevčenkova A., Balckars P., Ribickis L. Optimālās ātruma vadības un akustisko emisiju modelēšana intelektuālā elektriskā dzelzceļa transportā

Pētījuma mērķis ir izstrādāt jaunus matemātiskos modeļus un algoritmus intelektuālai elektriskā transporta sistēmai elektriskā ritošā sastāva optimālā ātruma vadībai, lai samazinātu vilciena akustiskās emisijas un elektriskās enerģijas patēriņu.

Autori piedāvā izmantot optimālās ātruma vadības algoritmu intelektuālai transporta vadības sistēmai, kas risina daudzvērtību optimizācijas uzdevumu pēc trokšņa samazināšanas un efektīvas enerģijas izmantošanas kritērija bez kustības saraksta traucējumiem. Piedāvātais algoritms ņem vērā arī optimālo elektroenerģijas patēriņu, kas tiek sasniegts ar optimālu un drošu elektriskā vilciena vadību, izmantojot intelektuālās iekārtas. Algoritms iekļauj sevī intelektuālo ātruma vadības procedūru un sarunas starp intelektuālām iekārtām.

Autori izstrādāja specifisko modelēšanas vidi, lai modelētu intelektuālās dzelzceļa sistēmas dinamiku un trokšņa un elektroenerģijas izmantošanas vadību.

Algoritmu un procedūru modelēšanas rezultāti parāda piedāvāto metožu efektivitāti dzelzceļa transporta uzdevumu risināšanā un dod iespēju samazināt elektroenerģijas patēriņu par 24% un samazināt akustiskās emisijas par 9%.

Gorobetz M., Levchenkov A., Balckars P., Ribickis L. Modelling of Optimal Speed Control and Acoustic Emission for Intelligent Electric Railway Transport

The purpose of research is to develop new mathematical models and algorithms for intelligent transport system for optimal electric rolling stock speed control to reduce acoustic emissions and consumption of electrical energy of the train.

Authors proposed to use optimal speed control algorithm for intelligent transport control system, which solves multi-objective optimisation task by noise reduction and energy saving criteria without infringements of the schedule. Proposed algorithm takes in account also optimal energy consumption that is achieved by optimal and safe control of electric vehicle using intelligent devices. The algorithm of optimal speed control is provided for train's agent. The algorithm includes intelligent speed control procedure and negotiations between intelligent agents.

The specific environment is developed by authors for the dynamic modelling of intelligent railway system for noise and energy saving control.

Results of modelling of these algorithms and procedures show efficiency of proposed methods in railway task solutions and give the possibility to reduce consumption of electrical energy by 24% and reduction of acoustic emission by 9%.

М.Горобец, А.Левченков, П.Балцкарс, Л.Рибикис. Моделирование оптимального управления скоростью и акустическими эмиссиями для интеллектуального электрического железнодорожного транспорта

Целью исследования является разработка новых математических моделей и алгоритмов для интеллектуальных транспортных систем для оптимального управления скоростью электрического подвижного состава, чтобы сократить акустические эмиссии и потребление электрической энергии поезда.

Авторы предлагают использовать алгоритм оптимального управления скоростью в интеллектуальных транспортных системах управления, которая решает многоцелевую задачу оптимизации по критериям снижения уровня шума и экономии энергии, без нарушения графика. Предлагаемый алгоритм принимает во внимание также оптимальное потребление энергии, что достигается за счет оптимального и безопасного контроля электрических транспортных средств с использованием интеллектуальных устройств. Алгоритм оптимального контроля скорости обеспечивается интеллектуальным агентом поезда. Алгоритм включает в себя процедуру интеллектуального управления скоростью и переговоров между интеллектуальными агентами.

Авторами разработана специфическая среда для динамического моделирования интеллектуальной железнодорожной системы для управления шумом и энергосбережением.

Результаты моделирования этих алгоритмов и процедур, показывают эффективность предложенных методов для решения железнодорожных задач и дают возможность сократить потребление электроэнергии на 24% и сократить акустические эмиссии на 9%.