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OPTIMISATION METHODS FOR DRIVING UNITS OF MOBILE ROBOTS

Abstract: *The different types of mobile robot undercarriages (locomotion mechanism of which is designed as a wheel, full-track, marching, hybrid or non-traditional one) have the different demands on electromechanical characteristics of an electric drive (e.g. torque moment, revolutions, electric current and voltage, gear ration etc.) and in following on an axis position of a driving undercarriage shafts and depending further components of the whole locomotion mechanism. The article has the aim to determine an optimal structure of a mobile robot wheel undercarriage as a non-emission vehicle on the base of a chosen optimisation method usage with a priority optimisation criteria - max. service time of the mobile robot actual task execution in a given technological scene (hence resulting divers design and energy sources), min. locomotion mechanism and driving unit mass, min. actual prices of individual driving unit parts (a monoblock), electromechanical quantities and other criteria. The article contents indicates the design of a monoblock draft: energy source - driving engine - gearing - electric quantities sensors - power electronics - intelligence control circuits, its phisical realisation and an experimental verification of planned (optimised) technical parameters. An own knowledge with the successful structure of the autonomous locomotion robots under the name of VUTBOT 1 and the physical mobile robot model MOBIL II is utilised, (research, development fabrication and service: VUT Brno, FS, ÚVSSaR).*

1.0 TASK FORMULATION

The word trend in a region of a practical robotics is the development, realisation and a use of mobile robotics systems in a different application areas (i.e. energetic, nuclear power stations service), mechanical engineering (automatic traffic and manipulation carriages), army and police usage (mobile means for an explosive manipulation), health service (carriages for auxiliary and attendance functions), etc. The mobile robotics systems (MRS in following) hereto work in an unknown or partially known environments (indoor and outdoor application), in many cases defined as a dangerous environment for a man, hereto a terrain may of a different nature (from a plane straight surface with the good carrying capacity up to watery soil or a stairs), lit. [1].

The basic MRS conception is created by:

1. **MACHINEWARE**, which contains: locomotion mechanism (undercarriage - wheel, full-track, legs, hybrid poss. non-traditional setting), own driving units, primary energy sources, electric board network, purpose superstructure
2. **HARDWARE**, which contains: electric power converters for driving units power, electronics for driving control, sensor subsystem, electronics for sensor subsystem control, energy source state monitoring, own MRS control systém
3. **SOFTWARE**, which contains: locomotion control, activity planning, navigation

regardless of at type or function of a mobile robot.

Nowadays there are no elaborated, generally known optimisation criteria and recommendations for a conception design of individual types of MRS locomotion mechanisms. Those are as a rule equipped with driving units, designated for other applications regardless of possibly accepted mayor or minor criteria. That is why it is possible to accept word problematic definition, which is to be solved in a complex way.

1.1 Solved Problematic Definition

In a electromechanical part structure (machineware) of mobile robots the subsystems and locomotion mechanisms (LM) are used, which secure mobile robot motion. Most used locomotion mechanisms are of a different arrangement of a wheel undercarriages, which can have 3, 4, 6 or more wheels. As the wheels it is possible to use classical ones or so called omnidirectional. The classical wheels may be driven or they are directionally controlled or are free rotational or their combination. Driving wheel (shaft, axle) is usually driven by so called driving unit monoblock consisting of the following structure: **energy source - driving motor - gearing - sensors - power electronics - intelligent control electronics.**

The problem is so implementation of theoretical derivation and analysis of conception optimisation of above mentioned driving unit monoblock structure and an experimental verification of chosen electromechanical drive parameters.

1.2 Solution Procedure And Expected Results

It is possible to divide the suggested solution procedure into mutually engaged grades in two solution regions and namely theoretical and practical ones:

1) Choice and use of a suitable mathematical model or optimisation method
2) Choice of optimisation criteria
3) Verification of optimisation criteria
4) Elaboration of optimisation results by e.g. use of multicriteria assessment of a design solution variants of the conception of mobile robots locomotion mechanisms
5) Determination of an optimal conception of electromechanical driving unit parts, determined for realisation for an execution of a technical experiment of driver verification parameters
6) Elaboration of a drawing documentation configuration and detail drawings of elaborated parts, determined for a physical monoblock assembly of a driving unit
7) Purchase of the needed components
8) Realisation of the measuring cabinet for a technical experiment
9) Technical experiment planning for determination of chosen driving units characteristics
10) Realisation of a technical experiment, i.e. measurement and identification of service electromechanical driving units, determined for mobile robots
11) Results elaboration and their generalisation for use of a theory and practise in a region of technical conditions at the design of mobile robots locomotion mechanisms

2.0 OPTIMISATION METHODS IN DESIGN ACTIVITY

An engineer solves frequently complex tasks at the design of new machines in the technological process control in which he decides about use of a goodly financial means, materials, costs and a human work, about a quality and competition ability of produced product. Nowadays it is not possible to support an important decision only by an intuition, possibly to rely on own previous knowledge. One of the most promising ways how to improve quality of the engineer work by an increase of the exact procedure share in the phase of decision and by acceleration an specification of timely cost routine work of the mechanical designer or draughtsman, presents the use of optimisation methods. As a very favourable looks the use of optimisation methods even at he design of a new technical objects or their improvement - e.g. optimisation of technical parameters, features and characteristics.

The analysis subject in every **optimisation task** are **optimisation variables** or **parameters.** In relation to a solved problem it may be following quantities (with examples):

- geometrical (dimensions: lengths, angles ...)
- kinematics (speeds, angular speeds, acceleration, rounds, ...)
- economical (purchase prices, service costs, ...)
- others (number of wheel teeth, ...)

The majority of optimisation variables may **change continuously** in **a** certain range, some can have only **discrete values** (e.g. allowable strength, number of teeth, etc.)

According to solved task the target (purpose) function may be e.g.:

- total mass of technical object structure (TO)
- space in which technical object exists
- time needed for TO start-up
- life-time
- value of power force or torque moment of TO
- TO power effect transferred to a basement
- uniformity of TO run
- TO production costs, etc.

The choice of a target function has the basic influence for the whole optimisation task result. The target function which may be expressed by the actual function, must have a minimal or maximal values, what is the sense of an optimisation. It so deals with the determination of function extremes.

For determination of function extremes it is possible to use different methods, which however are not generally replaceable according to a row of limits:

- analytical methods of one or more variables
- numerical methods for function of a one or more variables, without secondary conditions or with the secondary conditions in a shape of equation or roundness shape
- methods using penalty or barrier functions
- stochastic methods

3.0 DETERMINATION OF OPTIMAL VARIANT OF ELEMENT STRUCTURE OF MOBILE ROBOT LOCOMOTION MECHANISM DRIVING UNIT

3.1 Technical Systems Optimisation

The accomplishment of demands applied on driving unit is conditioned by the proper choice of element structure, assembled into a total (functional, assembly). About what total will most favourably fill demands laid upon, it is possible to determine by help of an optimisation, or optimisation methods give a possibility of an objective assessment.

In technical systems we can optimise from point of view of:

a) **technical** - technically most favourable variants
b) **economic** - service or other economic most favourable variants
c) **technical - economical**

This contribution will be in following dealing only with optimisation from point of view of technical most favourable variants or it is difficult to gain data about service features of the actual mobile robots. These data are dependent on actual application in corresponding technological scene and types of tasks, which mobile robot has to solve (in detail see [2]). The end user so must to weight a profitability inserted financial means of that or other offered variants of conception and so optimisation

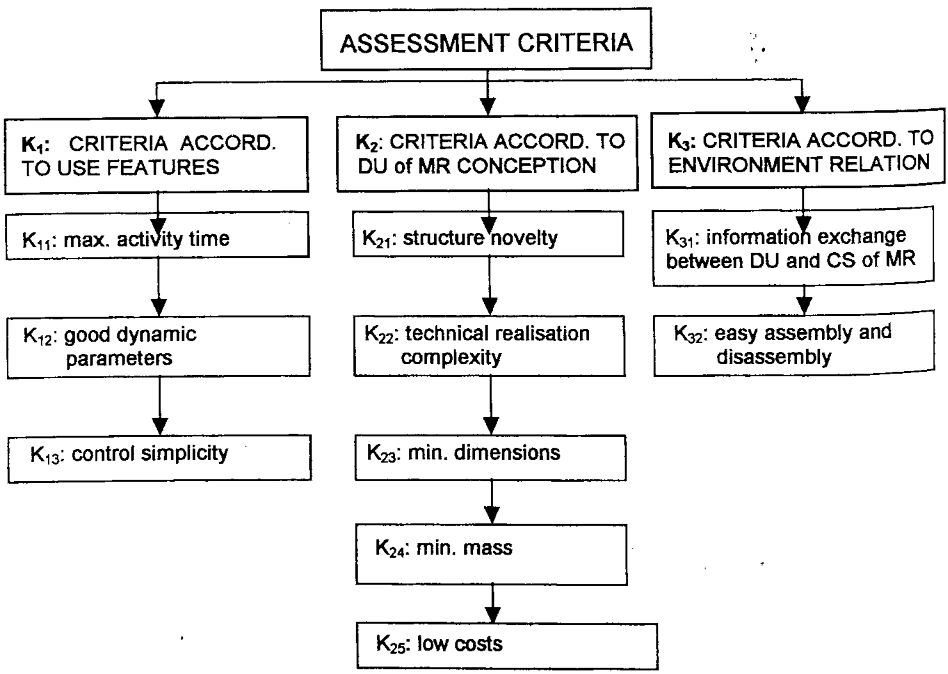
- from point of view of service, manufacturing and economical most favourable variants will not be provided for inaccessibility of serious data.

3.2 Determination Of Optimisation Criteria

Between **the main optimisation** criteria (i.e. demanded maxim and minima of chosen parameters, features and quantities), coming from demands on function and structure of driving units of mobile robots locomotion mechanisms belong:

- maximal time of mobile robot activity at the given energy supply in a primary source
- optimal mechanical characteristics on the shaft [e.g.: demanded characteristics M = f (n)]
- optimal dynamic parameters of an electromechanical system (e.g. dynamic parameters control in transient states or minimal start-up time of a mass in translation or rotation)
- minimal dimensions
- minimal mass
- maximal user comfort (simplicity of connection, control and supply)
- possible non-technical criteria: low costs in purchase of components, production and assembly of a driving unit.

Because the monoblock of driving unit (its element structure) is made out of elements, that are physically realised in a different way (different types of engines, gearing, brakes, sensors, control and supply electronics), a possibility exists to combine them into a complex (assembly). From these combinations only some of them will suit for a solution of this case, i.e. an optimisation should be dome. E.g. for driving unit design it is possible to chose besides above mentioned main criteria even **secondary optimisation criteria,** as it is seen in pict. 2.



Pict. 2: Main and secondary assessment criteria of locomotion mechanism of mobile robot driving unit

In the following paragraph there is issued an example of determination of chosen criteria from the reason of a shortage of a space.

3.2.1 Criteria according to utility features of a driving unit

- K_{11}: **criteria of maximal activity time of a driving unit** (possibly mobile robot) at given spare of energy in a primary source.

This criteria is given by relation of non-interrupted time of comparation variant activity S_e to a time of non-interrupted activity *t* (hours) of i-th variant S_i. Then it is possible to write assessment parameter of this criteria: $a_{11} = S_e / S_i$. Further it is necessary to formulate function K_{11} so, to express an objective assessment for all solutions:

1. optimal: more than 50 % increased time of non-interrupted activity, chose: $a_{11} = 0{,}67$ and $K_{11} = 100$
2. good: for 33 % increased time of non-interrupted activity, chose: $a_{11} = 0{,}75$ and $K_{11} = 70$
3. unacceptable: for same time of non-interrupted activity, chose: $a_{11} = 1$ and $K_{11} = 20$

A normalisation we provide by help of **an approximation by least square method.** An approximation function will be **exponential function.** Than criteria K_{11} has the shape after optimisation:

$K_{11} = 2724.a^{4,91} . e^{-4,91.a11}$

The same manner equations are derived even for following chosen criteria.

In the following optimisation procedure the values evaluation of the individual criteria K_{11} to K_{32} (most favourite is a table form) and determination of a relative mass *g* of assessment criteria *K*. The following step of determination of a partial optimisation grade in individual criteria groups according to relation: $K_{ji} . g_{ji}$ and $\Omega_j = \Sigma K_{ji} . g_{ji}$. Even here it is possible to use a tabular order of values of partial optimisation step in individual criteria groups K_1 to K_3.

3.4 Optimisation Results Elaboration

3.4.1 PATTERN Method

The method name is abbreviation of the full name Assistance Through Technical Evolution of Relevance Numbers (help in a planning by means of evaluation of significance relative values), which was chosen so, to give English word pattern, what means a model.

Procedure for method application:

- for chosen **parameters** their **weight of significance q** is determined best way by comparation method in a triangle of a pairs or by method of grading of parameters significance (experts give marks e.g. in range of 1 to 5 or 1 to 10) and by use of multicriteria evaluation by some of experts for more objective opinion acquisition
- **indexes of a change of parameter I_{ij}** is counted for every parameter according to a base parameter value H_{io} so the parameter improvement would be expressed by index increase as changes over value of 1,0. Expressing ability of this result may be improved so to express relative level in percents, when worst (comparable) variant presents value of 100%.
- **variants order** is determined.

3.4.2 Optimal variant of driving unit element conception determination

The optimisation of an element structure of driving unit is necessary to provide for all known structural and assembly elements, which fall into locomotion devices of mobile robot driving unit conception search. For simplicity it is introduced an optimisation of element structure PJ only from point of view of **gear box type.** The advantage of a **PATTERN** method at design variants evaluation is that it shows an optimal variant according to criteria and their weights, which were defined in here solved actual example, but from a general point of view it deals with a method quite universal one.

Variants evaluation, falling into consideration at application of suitable **structural design** (type) of **gear box,** is provided in following table 1.

3.4.3 Evaluation of optimal conception variant of driving unit element structure

From above mentioned example, when explicitly determined by help of PATTERN method, it was found that most favourite is harmonic gear box as driving unit component. It is clear further, that so it is possible to chose most favourite variant even for other driving units of locomotion devices elements so: **driving engine type, brake type, electromechanical quantities sensors types, converter type, intelligent control electronics type, energy source type.**

In relation with determination of partial optimisation grades in individual groups of our chosen criteria it is possible to determine theoretically **just optimal variant of mobile robot locomotion mechanism driving unit.**

Table 1:

No	PARAMETER	Unit	Mass q	spur gearing		planet gearing		harmonic gearing		cycloidal gearing		Note
1.	gearing ratio	[-]	**0.3**	2 1	0,3	3 1,1	0,33	5 1,2	0,33	4 1,2	0,36	
2.	torque moment M_K transfer from power P_N engine	[Nm]	**0.25**	3 1	0,25	4 1	0,25	4 1	0,25	5 1	0,25	
3.	dimensions	[m]	**0.3**	2 1,1	0,3	3 1,2	0,33	5 1,1	0,3	4 1,1	0,3	
4.	simplicity of engine connection	[-]	**0.1**	5 1,2	0,12	3 1,2	0,12	5 1	0,1	4 1	0,1	
5.	mass according to torque moment M_K	[-]	**0.05**	1 1,3	0,65	3 1,1	0,55	5 1	0,05	4 1	0,05	
	TOTAL S_J	1,00		0,765		1,085		1,12		1,06		
	RELATIVE TECHNICAL LEVEL			100%		141 %		146 %		138 %		
	ORDER			4.		2.		1.		3.		

Note:

- value meaning in table:

parameter value	weighted index Γ'_{ij}
change parameter I_{ij} index	

- scale of digital evaluation by parameter 1 to 5 with wording: 5-excellent, 4 - very good, 3 - good, 2 - sufficient, 1 - unsatisfactory

LITERATURE

[1] R. Knoflíček: *Mobile robot systems,* Internal textbook of Technical University of Brno, 1996, (in Czech)

[2] R. Knoflíček,: *Methodical design of mobile robotics systems electromechanical parts,* PhD Thesis on TU of Brno, 1996, (in Czech)