Automatic determination of soil parameters by robotic vehicles

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Abstract. The method for autonomous determination and estimation of soil parameters by robotic vehicles is described in the article. Basic requirements on the robotic chassis mathematical model allowing the estimation are listed. The main dependencies governing the interaction between the moving wheels/tracks and supporting ground are shown.

One of the promising trends in the development of the mobile robotic technologies is parallel and autonomous control of units, where the robotic chassis (RC) takes over, fully or partly, the human operator’s functions.

To implement this case, the on-board systems of the RC should be able to solve the following tasks:

\begin{itemize}
  \item remote determination of work zone geometric and basic ground characteristics;
  \item RC navigation and orientation within the work zone;
  \item estimation of the operational (local) and tactical (global) environment model parameters taking into account the operational (based on the on-board sensors) and a-priori (maps) information on the work zone;
  \item working paths (trajectories) planning and implementation on the operational and tactical levels;
  \item monitoring and fault diagnostics of software and hardware components of the on board control unit and power unit.
\end{itemize}

No robotic vehicle can operate successfully without soil parameters knowledge in its work zone. Therefore, the main intelligent control task to be considered in this article is basic ground characteristics estimation in the work zone. This task is of specific importance for the development of parallel and sequential driving algorithms for mobile robotic vehicles (figure 1).

For the driving planning system correct work, it is necessary to develop and implement the soil and geometry cross-country capability subsystem [1, 2]. To design the proper estimator, we need to define the mathematical model of the mobile robot motion in specific ground conditions (part of the vehicle floatation problem). The model should describe the robotic vehicle motion dynamics taking into consideration the measured input signals (angular velocity and driving wheels torque) during rough terrain manoeuvres completion, as well as features of the interaction of the wheels/tracks with a specific soil. The model should solve both the direct and the inverse problems in order to determine road and soil condition parameters on the basis of ground dynamic influences on the vehicle ground drive and to adjust the control effect accordingly.
The chosen mathematical model of the RC movement is a standard model [3] that meets the following requirements:

- the model should describe the joint dynamics of the vehicle body, power unit and the robotic vehicle driving system providing the accuracy necessary to assess the motion smoothness and the load on its elements;
- the model should consider design features of the suspension system and running gear including unretentive and non-holonomic character of the links imposed on the robotic chassis;
- the model should not impose restrictions on the characteristics of the vertical-plane route profile. It is required to study system dynamics when driving both on real ground irregularities and over artificial obstacles;
- the robotic chassis movement should be modelled with due consideration of soil resistance and adhesion, as the traction properties affect the vehicle speed.

The Bernstein-Letoshnev relation and the Janosi-Hanamoto relation (figure 2) are most often used to describe the soil in modelling the interaction process between wheels/tracks and supporting ground surface [4]:
The Bernstein-Letoshnev relation determines the vertical displacement of the running gear and the reactions occurring in the soil:

\[ p = C_g \lambda_y \]  

\( p \) – reaction pressure on the dF area;  
\( \lambda_y \) – soil pressure deformation;  
\( C_g, n \) – soil pressure parameters.

The Janosi-Hanamoto relation determines the tangential reactions in the soil during the movement of the chassis.

\[ \tau = (c + p \tan \varphi_g)(1 - e^{-\frac{\lambda_t}{\tau_{ss}}}) \]  

\( \varphi_g \) – internal friction angle;  
\( c \) – soil cohesion;  
\( \lambda_{ss} \) – shear constant;  
\( \tau \) – shear stress;  
\( \lambda_t \) – soil shear;  
\( p \) – reaction pressure on the dF area.

For description of the soil base, data on five parameters of the soil are required \((\varphi_g, \lambda_{ss}, c, C_g, n)\).

It is possible to get the soil current parameters in the contact spot by solving the inverse problem of terramechanics \([5]\), i.e. to estimate the soil properties analyzing the stress induced by dynamic influences of the surface support base on the running gear on the RC elements.

The longitudinal \((P_x)\) and lateral \((P_y)\) forces as well as the torque on the RC running gear, are estimated on the basis of the data from strain gauges mounted on the chassis suspension elements and wheels/tracks (figures 3, 4). The estimation algorithm is based on regression analysis. The error in the calculated values of the soil parameters does not exceed 14\%, i.e. the algorithm fits the purpose of \(P_x\) and \(P_y\) calculation.

**Figure 3.** Mounting of the strain gauges into the cavity of the connecting track pin.
Figure 4. Mounting of the strain gauges into the suspension element.

Therefore, optimal control of a robotic complex may be established and energy costs may be minimized despite the inevitably wide range of work zone soil conditions by continuous assessment of the RC work zone soil parameters.

References
[1] Mashkov K Yu, Rubtsov V I and Shitfanov N V 2012 Mobile robot flotation providing automatic system  BMSTU Bulletin S1 95-106
[2] Mashkov K Yu, Naumov V N and Rubtsov V I 2013 Soil characteristics automatic determination system for the dynamic interaction of the mobile robot chassis with a supporting surface Persp. Syst. and Manag. Problems. 86-95
[3] Naumov V N, Mashkov K Yu, Kotiev G O, Chizhov D A and Gorelov V A 2012 Robotic vehicles straight-line motion on deformable ground mathematical modeling algorithm Eng. Journal: Sc. and Inn. 11(11) 34-41
[4] Belyakov V V [et al.] 2004 All-terrain transport and technological vehicles. Fundamentals of motion theory N. Novgorod: TALAM 960
[5] Ojeda L [et al.] 2006 Terrain Characterization and Classification with a Mobile Robot Journ. of Field Rob. 2 103-122