Modelling the motion of a mobile robotic complex in the coastal zone

V S Makarov, A M Belyaev and V V Belyakov

Nizhny Novgorod State Technical University n.a. R.E. Alekseev, 24, Minin st., Nizhny Novgorod, 603950, Russia

1E-mail: makvl2010@gmail.com

Abstract. The article discusses the modeling of the curvilinear motion of a mobile robotic complex (MRC) with a caterpillar-modular mover on sandy deformable soil. Dependencies describing the main characteristics of the support base (modulus of elasticity, angle of internal friction, specific cohesion of soil, soil density) are given. The simulation was conducted in the Adams Tracked Vehicle environment. Shown are 3D views of the developed model of MRC. Typical sections of MRC curvilinear motion simulation on a sandy support base are considered. Graphs of changes in resistance to movement MRC are given for curved and straight sections. The calculations of the total resistance in a rectilinear motion and during rotation showed that the average values of the resistance to movement in a rectilinear motion are 1.6 kN with a curvilinear of 1.94 kN. The experimental values of the resistance force in a rectilinear motion were 1.45-1.7 kN. Thus, the maximum deviation between theoretical and experimental data was no more than 10%.

1. Introduction

Coastal zones can be monitored with the help of fixed stations, or research equipment installed on mobile robotic complexes (MRC). The most famous MRC is RTS-Hanna [1], which is designed to study the terrain in coastal zones and to capture the moment when the waves break on the shore. Mobile Mapping System [2] and Mobile terrestrial LiDAR [3] chassis are also used to study map data and to monitor wave parameters. The design of these MRCs is based on light vehicles, such as buggy. Of particular interest are the complexes based on all-terrain vehicles, like MRC built on [4] ARGO 8x8 platform. All the above-mentioned vehicles monitor nearby coastal zones. For remote coastal monitoring, the most common application is radar stations [5]. The chassis developed by NNSTU n.a. R.E. Alekseev [6, 7] has the best cross-country capabilities and features the whole equipment set required for successful operation. MRC data must correspond to mobility requirements in given traffic conditions. Scientists and researchers at Nizhny Novgorod State Technical University n.a. R.E. Alekseev see mobility as an integral operational property of transport-technological vehicles, which determines its ability to perform the task with optimum adaptability to operating conditions and technical condition of the vehicle itself, i.e. the ability of the vehicle to withstand external and internal factors which could impede fulfillment of the task [8]. This notion encompasses all previous concepts of mobility, and is a major notion in “mobility theory by Prof. Belyakov” [8].

To evaluate mobility, we can use a number of methods and apply various mathematical tools. One of the methods is to simulate motion in the Adams Tracked Vehicle (ATV) environment. However,
these calculations need to be confirmed on a real-life object. Such object is a mobile robotic complex (MRC) for coastal monitoring which was developed by the authors of this paper in the Laboratory of Modeling of Natural and Anthropogenic Disasters, NNSTU n.a. R.E. Alekseev [9-11]. The paper presents simulation of motion of MRC with a caterpillar-modular mover.

2. Model and Methods

MRC incorporates a body and four caterpillar modules, which consist of lower track wheels, final drive sprocket and caterpillar track. To build an MRC simulation model, we used the design documentation developed for the chassis. Geometric parameters and weight/inertial characteristics of the chassis, as well as such mover parameters, as the size of final drive sprockets, lower track wheels and caterpillar track, served as input data for the model.

ATV simulation exclusively allows to set a deformable support base. To build a deformable support base in ATV environment, we select the file with the soil properties [12-15] and preset characteristics from the database.

The file with deformable support base properties is a set of experimentally obtained coefficients pertinent to a certain type of soil. As input for the simulation, we used data from the experiments carried out during the expedition trips to Cape Svobodny, Sakhalin in 2016 and 2017 to test MRC efficiency for coastal monitoring [16-18].

Main input data are modulus of elasticity \(E\), angle of internal friction \(\varphi_s\), specific cohesion of soil \(C_s\), soil density \(\rho\). Some of these parameters are interconnected via empirical formulas (1), and can be calculated with the help of the penetration resistance value \(E_w\), N/cm².

\[
\begin{align*}
E &= 0.14 E_w + 4.47 \\
\varphi_s &= 12.27 + 0.033 E_w \\
C_s &= 0.0094 + 5.9 \cdot 10^{-5} E_w.
\end{align*}
\] (1)

Consequently, basing on the data [21, 22] we selected the following values for simulation: \(E_w = 60\) N/cm², \(E = 12.87\) N/cm², \(\varphi_s = 14.25\)°, \(C_s = 12.94\) kPa, \(\rho = 1.8\) g/cm³.

After recalculating the parameters and entering the relevant data, we built a sandy support base. MRC on a deformable soil is presented in Figure 1.

![Figure 1. MRC on a deformable soil](image)

MRC motion was simulated along the “U”-type path with typical 5 sections indicated in Figure 2.

Fugure 2 displays the following typical sections:
– section 1 – pulling away and accelerating up to a certain speed;
– section 2 – entering the turn;
– section 3 – steady curvilinear motion at a preset radius;
– section 4 – exiting the turn;
– section 5 – steady rectilinear motion.

For MRC motion simulation, parameters of the support base were set according to mathematically expected values for sandy coastal zones. In section 1, MRC accelerated up to 25 km/h. Then the vehicle entered the turn (section 2), switched to steady curvilinear motion (section 3) at 5m turn radius, exited the turn (section 4), and continued to follow the path in steady rectilinear motion (section 5).

As a result of these test drives, we obtained values of resistance to motion during the turn, and to rectilinear motion. The curves in Figure 3 show variation in total resistance during curvilinear (top) and rectilinear (bottom) motion. The average value for curvilinear motion is 1.94 N, and 1.6 N for rectilinear motion.

3. Results and discussion
The results obtained correlate with the experimental research [16-18]. The authors of this paper previously conducted experimental measurements of coastal soil parameters and resistance to MRC motion in given conditions. The data obtained helped to establish soil parameters which were then used as input data for simulation in ATV environment. Basing on the results of several measurements,
the average values of resistance to motion ranged from 1.45 to 1.7 kN with the mean value of 1.6 kN. These values were used to fine-tune the rectilinear motion of MRC in the model.

![Graphs showing resistance to MRC motion](image)

**Figure 3.** Variation in resistance to MRC motion on sand for curvilinear (a) and rectilinear (b) sections

### 4. Conclusion

As a result of simulation, we obtained the following results.

The model of MRC with a caterpillar-modular mover has been built in ATV environment. Rectilinear and curvilinear motion of MRC on a sand support base has been simulated.

The curves indicating time variations in model parameters have been plotted. The average value of resistance to curvilinear motion is 1.94 kN, and 1.6 kN to rectilinear motion.

Maximum deviation between theoretical and experimental data does not exceed 10%. Therefore, the use of the ATV software package is possible for assessing the mobility of a MRC with a caterpillar-modular mover in the coastal zone.

The simulation results obtained in the article are a logical continuation of the authors' earlier studies. Previously, experimental theoretical studies of the rectilinear movement of a MRC were carried out.
The use of the ATV software complex made it possible to calculate the parameters of the curved movement of the chassis with a caterpillar-modular mover.

Further research is related to simulation of on-the-spot turn, motion on other types of support bases (sandy gravel, snow and mixed), and evaluation of operational efficiency in coastal zones.

5. Acknowledgments
The results of the given study have been obtained with the financial support of the grants of the President of the Russian Federation, № MD-226.2020.8.

References
[1] Barber D M and Mills J P 2007 Vehicle based waveform laser scanning in a coastal environment Proceedings of 5th International Symposium on Mobile Mapping Technology Pradua, Italy
[2] Bio A et al. 2015 Methods for coastal monitoring and erosion risk assessment: two Portuguese case studies Journal of Integrated Coastal Zone Management 15-1 47 – 63
[3] Didier D et al. 2015 Coastal Flood Assessment Based on Field Debris Measurements and Wave Runup Empirical Model J. Mar. Sci. Eng 3 560 – 590
[4] Incoul A et al. 2014 Mobile laser scanning of intertidal zones of beaches using an amphibious vehicle INGEO 2014: 6th international conference on engineering surveying Prague, Czech Republic 87 – 92
[5] Coastal monitoring of the Okhotsk sea using an autonomous mobile robot Science of Tsunami Hazards
[6] Kurkin A et al. 2015 Autonomous Robotic System for Coastal Monitoring Twelfth international conference on the Mediterranean coastal environment (MEDCOAST 15) 1 and 2 933-943
[7] Zaytsev A et al. 2017 Coastal monitoring of the Okhotsk sea using an autonomous mobile robot Science of Tsunami Hazards 36-1 1-12
[8] Belyakov V et al. 2013 The concept of mobility of ground transport and technological vehicles Transactions of NNSTU n.a. R.E. Alekseev 3 (100) 145-175
[9] Kurkin A et al. 2017 Study of coastal soil surfaces of Sakhalin Island Paper presented at the 13th International MEDCOAST Congress on Coastal and Marine Sciences, Engineering, Management and Conservation, MEDCOAST 2017 2 775-785
[10] Kurkin A et al. 2017 Unmanned Ground Vehicles for Coastal Monitoring International Journal of Imaging and Robotics 17-1 64-75
[11] Kurkin A et al. 2017 Autonomous Mobile Robotic System for Environment Monitoring in a Coastal Zone Procedia Computer Science 103 459 – 465
[12] Ageikin Ya S 1972 All-terrain wheels and dual propellers. Theory and Design. Mashinostroenie (Moscow)
[13] Barakhtanov L V et al. 1996 Trafficability car (Nizhny Novgorod: NNSTU)
[14] Bekker M 1960 Theory of land locomotion (University of Michigan, Press)
[15] Wong J Y 2010 Terramechanics and Off-Road Vehicle Engineering (Elsevier)
[16] Makarov V et al. 2017 Study of trafficability conditions of typical soils of coastal zones of Sakhalin Island (Russian Federation) Paper presented at the 19th International and 14th European-African Regional Conference of the ISTVS
[17] Belyakov V V and Makarov V S 2020 Study of efficiency of a 6x6 all-terrain vehicle in coastal zone Paper presented at the IOP Conference Series: Materials Science and Engineering” 709(4) doi:10.1088/1757-899X/709/4/044030