ISSN: 1231-4005
e-ISSN: 2354-0133
DOI: 10.5604/01.3001.0012.4329

A MOBILITY ANALYSIS OF USING THE RHEX-TYPE MOBILE ROBOT IN VARIOUS SURROUNDINGS

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Abstract

Mobile robots are becoming increasingly popular, finding a great deal of applications, especially in situations where conventional mobility systems, such as wheels or tracks, prove ineffective. Exploration of an unknown environment or a place, in which Man is incapable of staying, for example exploring remote planets in the Solar System, is often linked with operating a device in a rough terrain. This requires an adjustment of the robot locomotion system to the ground. The problem of high mobility in diverse surroundings is still a major challenge. Therefore, the concept of mobile robots is extremely popular and is still being developed. Using this type of propulsion carries several advantages, namely the possibility of applicability of this type of solutions in an environment, which is not easily accessible to wheeled vehicles (sandy, mountainous terrain, etc.). There is still a large interest of constructors and scientists in unconventional drive systems, adapted directly from nature, which often offers very efficient solutions. Quite frequently, designers copy the construction of animal locomotion system, attempting at implementing them in their designs. The aim of this article is to present an original construction, known as the Rhex-type robot in the available literature. In addition, it presents a number of conducted investigations, which describe the platform's mobility in various terrains, such as sands, rocks and rubbles, as well as the possibility to overcome the terrain obstacles. It ends with conclusions and potential application areas of this type of a design.

Keywords: *mobile robot, Rhex, mobility, animal locomotion system*

1. Introduction

The article presents a prototype of a technical solution in which the locomotion mechanism was designed so as to reach high mobility in a varied terrain. It is a mobile robot known as Rhex [5]. The article also provides test results related to moving around a varied terrain and unusual obstacles. It briefly describes ways of controlling and moving the device. The construction known as Rhex is composed of three segments, which are connected by means of a spring hinge. It has six legs of a specific shape, which are driven by DC motors with a gearbox [1]. This is an unconventional approach to the problem of the mobility of robots.

A mobile machine is defined as a vehicle, where the contact of the leg with the ground is discrete in time domain, which means that the machine leaves a discontinuous track on the ground, over which it is walking. When in motion, some legs have contact with the ground by creating the so-called polygon of stability, whose tips are at the point of the contact of the leg with the ground. The more feet placed on the ground, the more tips of the polygon, which directly affects the stability of the robot's movement. The more static algorithm of motion, the more stable movement of the device. Along with the increase in the dynamics of the robot's locomotion and fewer legs, which support the device, the polygon of stability may only have three tips. Therefore, high dynamics of mobility can cause a shift in the centre of gravity of the device outside the polygon, which will result in the loss of stability and lack of the possibility to continue the movement [1, 5, 7]. The problem of stability has been illustrated in the diagram below.

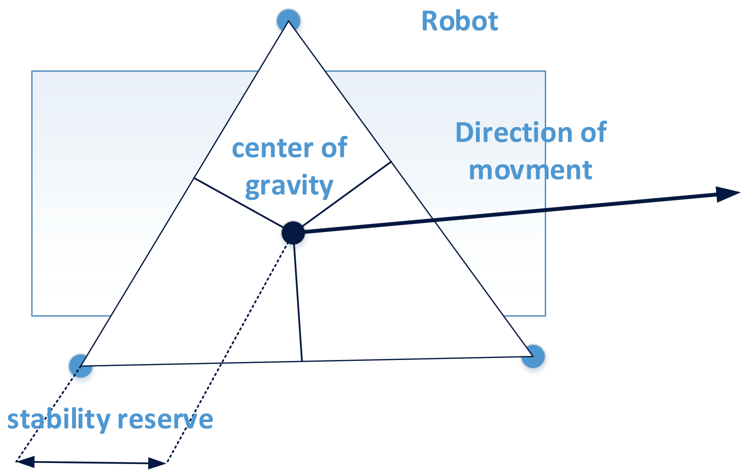

Fig. 1. Polygon of stability [1, 7]

2. Design of the mobile robot Rhex

The design of the mobile robot was made using the Solid Edge ST5 software, which also allowed carrying out a simple simulation of the dependency among the various segments of the robot. The three modules of the design, which are inspired by the segmented body part of insects, are connected to each other by spring hinges. This type of a connection enables the segments to work independently as well as adjusting the platform to uneven terrain. It also facilitates climbing obstacles (during the tests the robot climbed over an obstacle of a similar height to itself). The legs have a special shape, which allows achieving high mobility in varied terrain. They were printed on a 3D printer as many other parts of the construction. Thus, it was possible to obtain little weight while maintaining significant strength and elasticity. The limbs are powered using DC motors with gearboxes. The engines are controlled from the Atmega32 microcontroller by a 2-channel motor driver. The generated PWM signals allow a variable speed adjustment of the motors, however, the inertia of the gearbox enforces application of the trapezoidal speed profile which consists in a gradual increase in the rotational speed until reaching the set speed, when braking – a gradual reduction. The control system was designed in the Eagle 5.11 programme in the form of a printed circuit, two-sided (PCB) in the technology of THT assembly of parts [1]. Below is a design of the device (Fig. 2) and a ready prototype (Fig. 3).

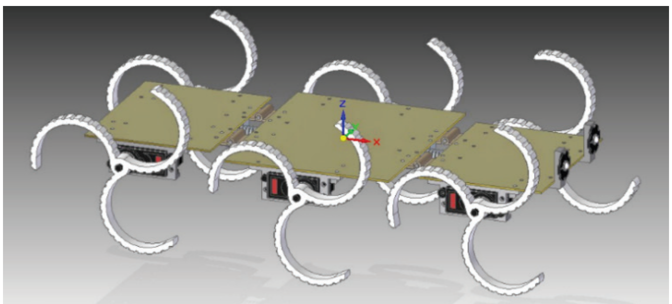

Fig. 2. Robot design in the Solid Edge ST5 programme [1]

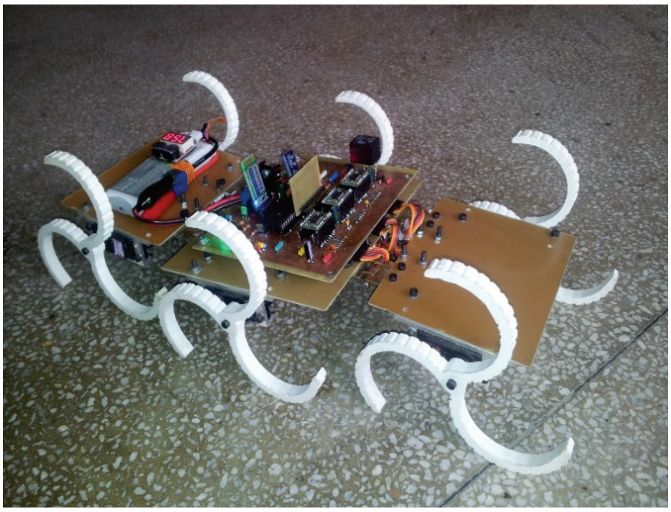

Fig. 3. Physical model of the device [1]

The entire device is battery-operated with a lithium-polymer battery. The robot is controlled with a remote control, for communication using simple Bluetooth modules configured with special AT commands, as Master and Slave [4].

3. Control algorithms

In order to ensure the best possible control, the device propulsion was divided into two groups, the left and the right one, three drives on each side. In the same configuration, each group of the drives is controlled by two independent PWM signals, generated by the microcontroller, and sent on through the 2-channel motor controller. In addition, it is possible to control the direction of revolving each of the separate legs by a proper signal configuration transmitted on 2-channel motor controllers. Due to such a solution, the robot is capable of turning when stationary through an antagonist movement of particular groups of drives. Moreover, due to a variable adjustment of the control signal PWM, it is possible to make a turn when running through differentiating signals of the propulsion groups (e.g. the left drive group is moving faster than the right one, as a result of which there are voids made by the gravity centre, at an appropriate radius R). The larger difference between control signals PWM1 and PWM2, the greater is the radius of the arc made by the platform [1]. Fig. 4 shows the mechanism of arc formation.

4. Investigations and observations

When preparing the investigations, the author determined the maximum speed of the robot. Since the rotational speed was known from the geometry of the legs, it was possible to calculate the maximum theoretical speed of the device (reference speed) for PWM control signal = 100%. The pulse width modulation allows variable control of the rotational speed of the DC motors [6]. The author specified two types of investigations that will be carried out. The first type of the investigation is to determine the speed with which the device can move depending on the control signal PWM in different field conditions. In order to conduct the investigations, a two-metre long section of the path for the device to cover was determined, moving straight ahead along the designated line. The time of covering this section was measured, on the basis of which the actual speed of the device in the function of the changing PWM signal was calculated. The speed of the device was calculated from the relationship [4]:

$$V = \frac{S}{t}, \tag{1}$$

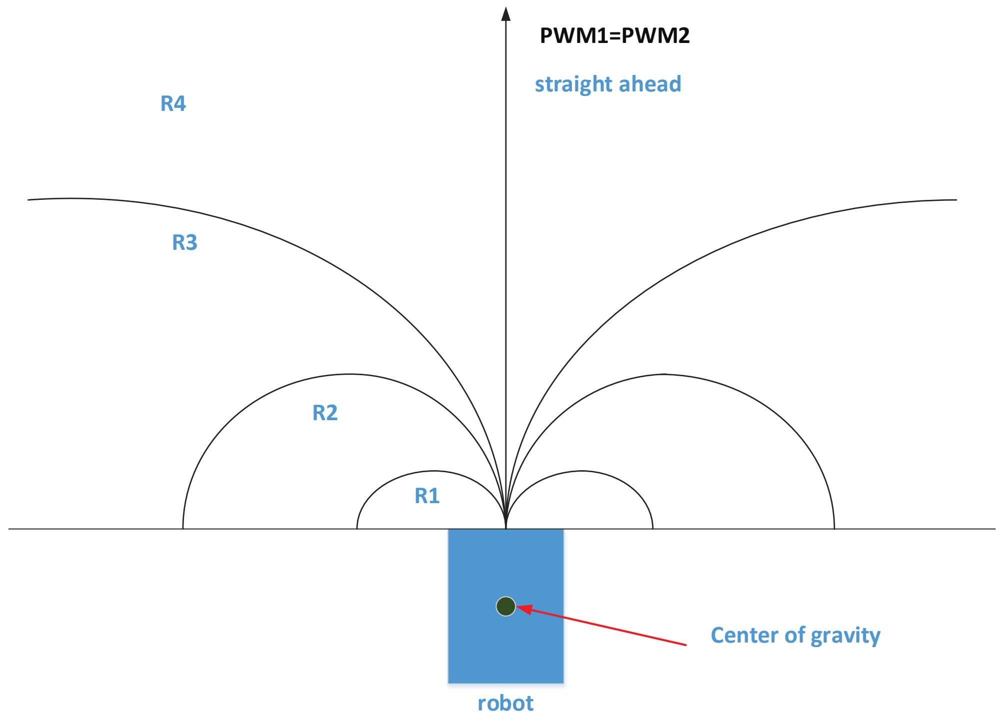

Fig. 4. Principle of turning along an arc [1]

where:
V – indicates speed,
S – the path,
t – the time measured in seconds.

However, due to the trapezoidal profile of velocity, a buffer section was added, 0.5 m long, before the measuring section, so that the robot moves at a constant set speed when mobile along the route [1]. The principle of testing and the idea of a trapezoidal profile of speed are depicted in Fig. 5 and 6, respectively.

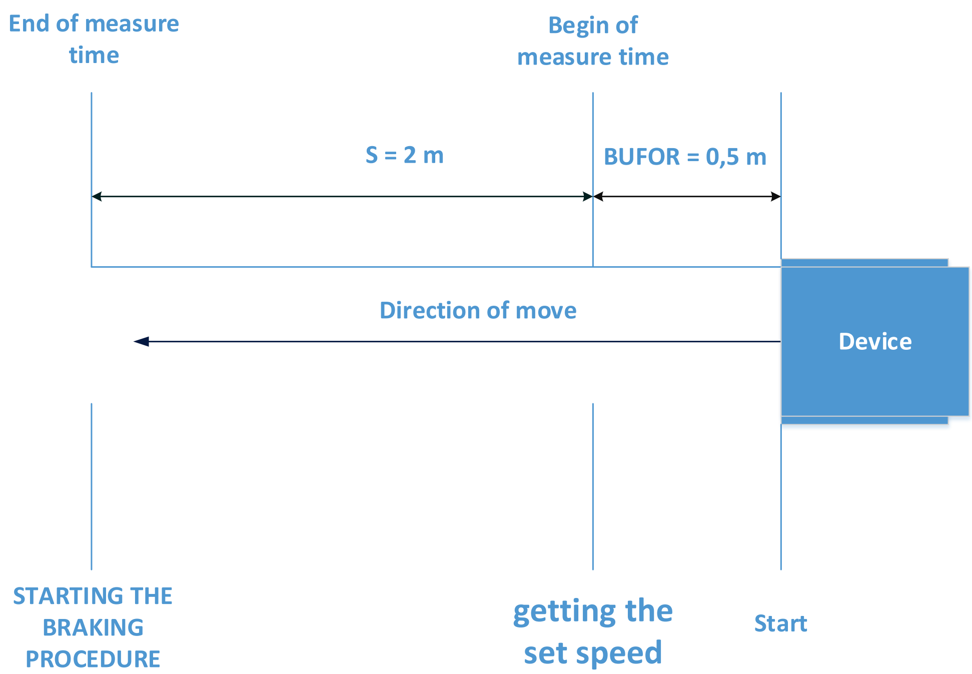

Fig. 5. Principle of conducting investigations [1]

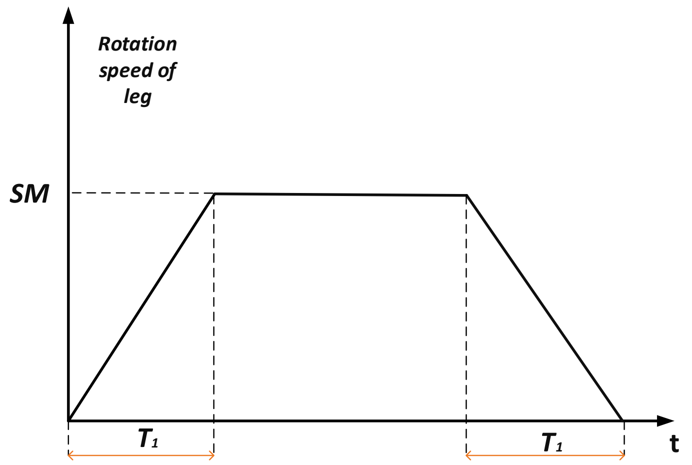

Fig. 6. The idea of a trapezoidal speed profile [1, 7]

The second kind of the investigation is a type of observation, which consists in determining what natural and artificial obstacles, have, or have not, been overcome by the device. The robot tried to overcome various types of obstacles when directly heading at them. The listing of the obstacles has been presented in a tabular form with a note whether the obstacle was overcome by the robot (Tab. 1) [1].

The terrain, in which the robot was tested, is as follows: rocks, sand, lumps-rocks, woodland, grass and artificial surfaces such as parquet, rubber, and ceramic tiles. The table below is a summary of the obtained findings.

Tab. 1. Investigation results [1]

Listing of measurements			Type of terrain							
	Theoretical	PWM [%]	Stones	Sandy	Woods	Grass	Parquet	Ceramic tiles	Rubber surface	Lumps-rocks
			Speed designated empirically							
Speed V [m/s]	0.18	30	0.14	0.15	0.15	0.15	0.18	0.18	0.18	0.13
	0.25	40	0.20	0.20	0.21	0.21	0.24	0.24	0.24	0.17
	0.3	50	0.25	0.25	0.26	0.27	0.29	0.29	0.31	0.21
	0.36	60	0.29	0.29	0.29	0.32	0.35	0.35	0.36	0.24

One may observe a dependency that artificial surfaces achieved similar results to theoretical speeds, whereas more varied surfaces significantly differ from these values. This is due to an uneven and much greater payload of the legs. The device moves best over a rubbery surface (speeds which are theoretically determined overlap those measured ones during the tests), and the worst in lump-stone terrain. The investigation was conducted for four values of the PWM signal, which controls the work of the motors.

Conducting this type of investigations will allow specifying the profile of the robot's mobility, which will exactly determine what types of obstacles are to overcome. Below in a tabular form, there are investigation results, which have the character of an observation. The table is constructed as follows, on the left-hand side there is a column with the name of an obstacle, followed by a brief description. The column "obstacle type" indicates whether the obstacle is artificial or natural. The column "comments" specifies whether the obstruction was overcome by the mark (✓); when it was not overcome – by the mark (x) [1].

Tab. 2. Tabular summary of terrain obstacles - observations [1]

No.	Name	Obstacle type	Description	Remarks
1	Curb	artificial	Concrete curb, 16 cm high	✓
2	Felled trunk	natural	Felled trunk, 35 cm in diameter, 25 cm in height and 15 cm in height	✓
3	Lying branch	natural	Branch of 25 cm circumference	✓
4	Artificial printer		Office printer, 17 cm high	X
5	Cardboard packaging	artificial	Cardboard packaging 33×21 sized, 12.5 cm high	✓
6	Elevation	natural	Natural elevation of 35 cm relative height preceded by a trench, 13 cm deep and 40 cm long	✓
7	A bottle of water	artificial	A bottle of water – 1.5 l capacity; 8.8 cm in diameter	✓
8	Two bottles	artificial	Two bottles of water distanced from each other by approximately 25 cm, 8.8 cm in diameter	✓
9	Stone area	natural	Area, where there are many stones of different sizes	✓
10	Lying curb	artificial	Lying curb measuring 100×30 cm and 13 cm in height	✓
11	Stone	natural	Single stone with a length of 10 cm and 6 cm in height	X
12	A group of stones	natural	Four stones placed one on another, 14 cm high	✓
13	Artificial ramp		Ramp, 590 cm long, 160 cm high (elevation angle 16^o)	✓
14	Fissure	natural	Stone fissure, 15 cm wide and 8 cm high	✓
15	Rails	artificial	Railway	X
16	Thicket	natural	Thicket – 30 cm high	✓
17	Embankment	natural	embankment: 80 cm long and 35 cm high	✓
18	Stone steps	artificial	Five stones with a diameter of approximately 40 cm arranged at different levels	✓
19	Stone fissure	artificial	Two stones arranged at similar levels, forming a fissure	✓
20	Lying tree trunk	natural	Tree trunk, 40 cm in diameter	X
21	Boulder	natural	Steep boulder, 60 cm in length	X
22	Concrete slab	artificial	Board of 25^o inclination, 60 cm long with a steep driveway	✓

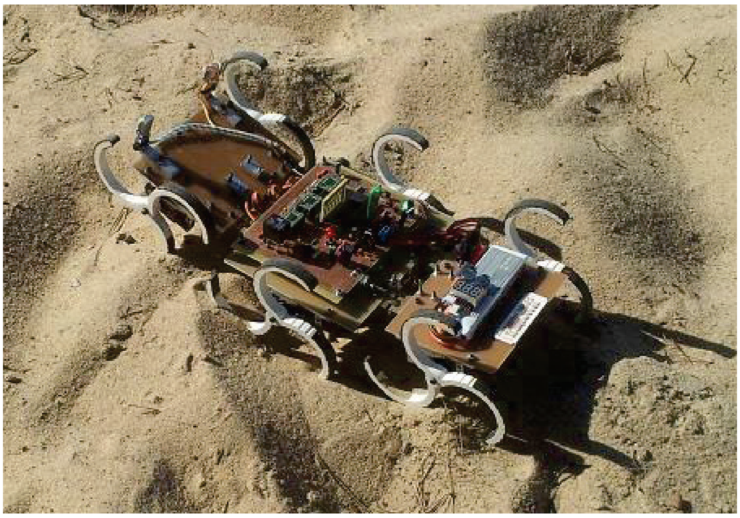

Fig. 9. Robot Rhex in difficult field conditions - sandy terrain [1]

5. Conclusions

The aim of the conducted investigations was to evaluate the capability of mobility devices in different field conditions as well as testing various terrain obstacles. The unique design of the propulsion and its construction allowed obtaining high mobility of the robot over varied surfaces (the device covered all types of the surface). Besides, the device is able to overcome various field obstacles.

During the investigations, it was observed that the area, over which the device is moving, exerts an impact on the speed of the movement. More varied terrain means larger load of the drives. In addition, moving along a bumpy terrain causes loss of synchronisation of the limbs, which may affect the deviation of the direction of movement of the robot. Lack of synchronisation is caused by unequal limb loading. It is possible to eliminate this negative phenomenon by checking the synchronisation of limbs using additional sensors and changing the software. A number of natural and artificial obstacles were overcome by the robot. It was observed, however, that there is a possibility of hanging the device over an obstacle, causing a lack of a possibility for further mobility. One of the artificial obstacles which needs special attention is a pavement curb, 16 cm high, which was easily overcome by the robot (the height of the obstacle equalled the height of the robot).

One of the areas of application of the device of such a high capacity to cover varied terrain might be the use of the robot as a mobile scout equipped with a camera and various sensors, which allow the detection of contamination or sampling material for investigations. Similar constructions may be used to explore the unknown and undetected environment (remote planets). Another application of the device might be applying the construction to transfer explosives in order to destroy tanks or armoured vehicles. Any place where human exposure is associated with risk and danger of loss of health or life may be a potential area of application of the platform after it has been equipped with the right components.

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Manuscript received 04 June 2018; approved for printing 07 September 2018