Some tasks require accurate movement of loads when the vehicle acceleration transmitted to the load is limited and the load needs to be moved over a rough terrain. This problem may be solved either by improving the quality of the wheel suspension (by using a softer suspension), or by using a purely walking mechanism. This paper suggests a new approach that combines wheeled and walking mechanisms. Walking algorithms are used for rough terrains, while traditional wheels are used for flat surfaces. Such approach for the wheeled and walking platform may be used for various purposes – from elimination of the consequences of accidents and disasters (transportation of the wounded persons) to exploration of natural resources.

Wheeled and Walking Platform Motion Algorithm

Ivan Anatolievich Vasiliev and Alexander Vladimirovich Popov*
Central Research and Development Institute of Robotics and Cybernetics, Department 32, Saint Petersburg, Russian Federation; s.nikitin@rtc.ru

Abstract

Some tasks require accurate movement of loads when the vehicle acceleration transmitted to the load is limited and the load needs to be moved over a rough terrain. This problem may be solved either by improving the quality of the wheel suspension (by using a softer suspension), or by using a purely walking mechanism. This paper suggests a new approach that combines wheeled and walking mechanisms. Walking algorithms are used for rough terrains, while traditional wheels are used for flat surfaces. Such approach for the wheeled and walking platform may be used for various purposes – from elimination of the consequences of accidents and disasters (transportation of the wounded persons) to exploration of natural resources.

Keywords: Algorithms, Robotics, Robot, Wheeled and Walking Platform

1. Introduction

The need for sustainable motion of various mobile platforms over rough terrains points out obvious insufficiency of the traditional ('classic') types of propulsion sources, including wheeled, tracked, combined wheeled and tracked vehicles and other types of devices.

The wheeled and walking system shown in Figure 1 is proposed for the improved performance.

Each wheel is installed on a manipulator with 2 degrees of freedom, which allows controlling the drive system in a wide variety of ways.

Some tasks require careful transportation of loads on uneven surfaces. 'Careful transportation' means a motion in which the load is experiencing minimal acceleration in all directions and axes.

2. The Conceptual Basis of the Method

In order to achieve accurate motion of the platform on an uneven surface, the motion itself is performed by the rotating manipulator joints, on which the wheels are installed. The wheels are required in order to provide support to the underlying surface. The platform moves forward at the same speed.

Figure 2 shows motion of the platform drive gears. This figure demonstrates that wheel 1 is moving to the initial, i.e. the most advanced forward position. Such motion is known as a translational motion. The other wheel, which is approaching the end of the range, is, probably, wheel no. 3. It is followed by wheels no. 5, no. 2, no. 6 and no. 4. Then the sequence is repeated.

Once wheel no. 1 moves forward and is able to provide the required support force on the underlying surface, wheel no. 3 will start the translational motion. The entire platform is moved only as a result of motion of the wheel manipulators. Of course, such type of motion is justified only for driving on an uneven surface, because the required smooth ride quality is achieved by simple rolling of all six wheels.

Figure 3 shows a motion sequence diagram for all wheels. Such sequence diagram shows translational motion using semi ellipses, and regular motion of manipulators is shown by straight lines.

3. Solution of the Problem

Let us formulate quantitative relations for such motion. Assume the following length parameters of the wheel manipulator links: Shoulder (first) link – a, elbow (second) link – b. Suppose also that the platform clearance is h.
Therefore, the angle at which the wheel is raised to the desired height will be as follows:

\[ a_1 = -\arcsin \left( \frac{h - m}{a + b} \right) \]  

(1)

Changes in the angles of the shoulder and the elbow in order to move the wheel along a straight line should be made according to such laws:

\[ a = v_x t, \]

(2)

\[ \beta = a + \arcsin \left( \frac{h - m - a \sin(a)}{b} \right), \]

(3)

Where:

- \( v_x \) is speed of change in the shoulder angle;
- \( t \) - time.

In order to change the angles of the supporting wheels, the linear (i.e. translational) speed of the platform \( v_{x}^{17} \) should be introduced. The actual height of the shoulder joint rotation axis above the support is denoted by \( h_1 \). Then we have:

\[ h_1 = (a + b) \sin a \]

\[ s = (a + b) \cos a \]

\[ y_1(t) = (s - v_x t) \]

\[ a_1(t) = \arctan \frac{y_1(t)}{h_1} \]

\[ l(t) = \sqrt{y_1^2(t) + h_1^2} \]

\[ \beta(t) = 360^\circ - \arccos \frac{a^2 + b^2 - l^2(t)}{2ab} \]

\[ a_2(t) = \arccos \frac{a^2 + l^2(t) - b^2}{2al(t)} \]

\[ \alpha(t) = 90^\circ + a_1(t) + a_2(t) \]
Time-dependent values in chain (4) are clearly identified as time functions. \( h \) and \( S \) are the initial parameters, i.e. they are estimated once – at the end of the translational motion when the wheel is leaned upon the underlying surface.

4. Discussion
Using chain (4), the desired quality of the mobile platform motion may be achieved, as the platform does not ‘ride’ on the surface, but is moved by the much more accurate manipulator wheels.

One aspect here needs to be taken into account. Let us look at Figure 5.

This figure shows a top view of the Mobile Robotic Platform (MRP). Support wheels are shown in green, and the translational wheel is shown in red colors. Light brown dashed lines show the geometric center of the platform, and the blue quadrangle shows the zone of stability, in which the platform center of mass (so the platform does not tilt) may be located at the moment. If we define the intersection of all 4 possible zones of stability, we will get a purple diamond, shown in the center\(^{16,19}\). The center of mass (gravity) of the platform-load complex should be located within the diamond.

At the time of the wheel separation from the support (first translational motion), and at the time of pressing it to the support (after translational motion) due to the fact that the load starts to be distributed in another way, slight oscillations may be observed.\(^{13,15}\)

This effect can be minimized if we start moving the next wheel in concert with the moving one. Moreover, the other wheels may play a little bit. Manipulator wheel drive gears are equipped with a force sensor, so that this method is quite feasible.

5. Conclusion
Modeling of this method showed its complete feasibility. Moreover, the described platform with a load may automatically switch from the wheeled mode to the walking mode. This will not require any additional sensors – torque sensors in drive gears would be enough.

When driving on a flat surface, efforts in the joints of the drive gears are constant and depend only on the location of the center of mass of the platform-load system. When the platform starts running over an uneven surface with one wheel (in any case, only one wheel will be the first to collide with the uneven surface), these efforts in the joints will change. Maximum torque change will be observed for the first wheel running over the uneven surface. The algorithm of the walking start will change in such a way that the first wheel becomes the first walking wheel.

Unfortunately, it is impossible to solve (from the algorithmic point of view) the problem of defining the transition from a rough terrain to an even surface using the torque sensors in the joints\(^9\). Other approaches and sensors of the external environment (such as machine vision) need to be applied for this purpose.

The main limitation of such approach is obvious: Very uneven terrain, i.e. such one when the wheel suspension manipulators have insufficient dimensions (and the platform frame clearance) in order to compensate for roughness.

Such algorithms may be applied to any transport tasks with uneven surfaces, particularly for premises.

6. Acknowledgements
This article was prepared with the financial support of the Ministry of Education, Agreement no. 14.578.21.0047 RFMEFI57814X0047 providing a grant for implementation of 2014-2020 Priority Technological Research and Development in the Russian Federation federal target program.

7. References
1. Burdakov SF, Miroshnik IV, Stelmakov RE. Wheeled robot motion control systems. St. Petersburg: Nauka; 2001.
2. Briskin ES, Chernyshev VV, Maloletov AV, Sharonov NG. Comparative analysis of wheeled, tracked and walking machines. Robotics and Technical Cybernetics. 2013; 1:6–14.
3. Kozorez DA, Kruzhkov DM. Components and structure of autonomous control systems of a robotic car prototype.
Specialized Machinery and Communications. 2012; 3:15–8.
4. Pavlovskiy VE, Ogoltsov VN, Ogoltsov NS. Lower level control system for manual transmission vehicles. Preprint IPM 103. Moscow: 2013.
5. Vasiliev IA, Lyashin AM. Analytical solution of the reverse kinematic problem for six-link robotic manipulators. Automation in Industry. 2008; 10:3–5.
6. Andre P, Kauffmann JM, Lhote F, Taillard JP. Robot Technology. Moscow: Mir; 1986.
7. Artbolevskiy II. Theory of mechanisms and machinery. Moscow: Nauka; 1975.
8. Belyanin PN. Kinematic schemes, systems and elements of industrial robots. Moscow: Mashinostroenie; 1992.
9. Belyanin PN. Industrial robots and their application. Moscow: Mashinostroenie; 1983.
10. Belyanin PN. Status and development of robotic technology. Problems of Machine-building and Machinery Reliability. RAS. 2000; 2:85–96.
11. Burdakov SF. Elements of the robotic theory. Mechanics and control: textbook. Leningrad: LPI Press; 1985.
12. Veselovskiy VV. Kinematics of manipulators. Moscow: MIERA Press; 1991.
13. Vulfson II. Oscillations of machinery with cyclic mechanisms. Leningrad: Mashinostroenie; 1990.
14. Zenkevich SL, Yushchenko AS. Robot control. Basics of controlling manipulator robots. Manual for high schools. Moscow: Bauman MSTU Press; 2000.
15. Kozhevnikov SN. Dynamics of machinery with elastic linkage. Kiev: USSR AS press; 1961.
16. Kolovskiy MZ, Slouschh AV. Basics of industrial robot dynamics. Moscow: Nauka; 1988.
17. Korendyasev AI. Manipulation systems of robots. Moscow: Mashinostroenie; 1989.
18. Zegzhda SA, Soltakhanov SHH, Yushkov MP. Nonholonomic system motion control and variational principles of mechanics. New class of control problems. St. Petersburg: SPbSU Press; 2002.
19. Khof M. Industrial Robotics Handbook. Moscow: Mashinostroenie; 1990.
20. Siciliano B, Khatib O. Springer Handbook of Robotics. Berlin: Springer-Verlag Berlin Heidelberg; 2008.