WHEELED ROBOT FOR RURAL ENVIRONMENT

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Abstract. In this paper solutions are proposed to improve the performance of a wheeled robot for rural environment. These solutions can be used for a wheeled mobile robot that moves upon curved surfaces, surfaces with irregularities and small coefficient of static friction between the wheels and the surface. The design and control of the robot are based on a new concept of a wheeled mobile robot, which can work in two different modes.

Keywords: mobile robot, design, control, changeable structure.

Introduction

The rural environment is characterised by working surfaces with uneven terrain (sand, mud or snow). Legged robots are used normally for such kind of surfaces; however they have a very complex construction. Among some of their features are: usually they are working with on-board computer, they have numerous DOF, they have low efficiency, very high energy expenses and low autonomy, and, in general, they are very expensive and act with low velocity [1].

On the other hand, wheeled robots are of a comparatively simple construction, they are not expensive, their efficiency is high, they can work with high velocity and usually they have a simple control system. However, they can move only over solid and smooth surfaces without voluminous obstacles [2-6].

The authors of several studies [7-9] attempted to mix positive properties of legged and wheeled robots. Normally, it is done on the base of a legged robot connecting wheels at the end of the legs. This kind of robots is called hybrid robots. Hybrid robots can have high velocity over smooth surfaces and use legs to cross obstacles. However, they usually have a very complex design, even more complex than legged robots; they also have a complicate control system, they require a large number of motors, etc.

In this paper we consider a new configuration of a mobile robot, which takes the advantages of positive properties of both wheeled and legged robots. The construction of the robot is based on a new concept of design of wheeled mobile robot, which can work in two different modes.

The first mode implies that the wheeled mobile robot has as many independently controlled traction motors as wheels. In this mode the robot works similarly to the go-anywhere vehicle [10].

The second mode of movement is used when a surface is extremely difficult (sand, mud or snow) and, if using the first mode, the robot starts to stick. In this mode the distance between wheels is changeable with a help of additional motor; the wheels of the robot act alternately as supporting legs (blocked wheels) or as freely rolling wheels [11].

Design of a robot for the first mode of movement

Usually, the design used for a wheeled (normally three-wheeled) mobile robot includes two motors: one power motor and one steering motor on the same wheel [12-14], or two power motors on different wheels, with a third wheel having passive steering [15-17]. Such design demonstrates a good performance while a wheeled mobile robot moves upon a surface with high enough coefficient of static friction and not very big coefficient of rolling friction.

It is reasonable to use wheeled robots with improved traction forces for rural environments because movement on uneven terrain with small coefficient of static friction can produce slippage of traction wheels and sticking of the robot. To prevent slippage it is necessary to increase the traction force. The traction force can be easily increased by having as many traction motors as wheels. However, consequently, it is necessary to have a special kind of control.

On Figure 1 a three-wheeled robot is shown with three traction motors and one steering motor. Each of the motors has optical encoder, connected with the control system. With a help of these encoders, the control system can have information on the position of the steering wheel and velocity of traction wheels. Each traction motor contains a sensor of torque (in the simplest case current sensors can be used). Additionally, each wheel has a sensor of normal force for calculation of distribution of forces between wheels.

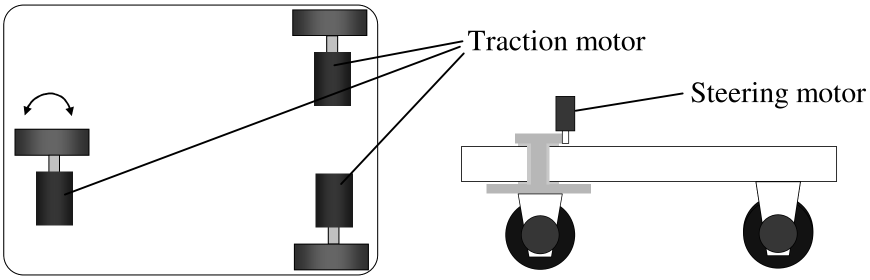

Fig. 1. **Mobile robot with three wheels and four motors**

The direction of the robot motion is determined by the control system by standard methods and is out of consideration in this work.

Conventionally, the wheeled mobile robot movements are either velocity controlled or torque controlled. However, in the specific case, when a robot has as many traction motors as wheels, neither of the known algorithms satisfies completely the requirements. For a velocity control mode it is very complicated to estimate the correct desired velocity for each wheel since the mobile robot moves upon an uneven surface. The second possibility represents a good choice to solve the control problem. Controlling torques applied to wheels, the wheels can be prevented from sliding on low friction coefficient surfaces. However, it is not enough because a very important thing is that the robot moves with a suitable velocity to perform the tasks efficiently (for example, to move with a constant velocity). Therefore, not only an accurate velocity control must be provided but also a torque control is required in order to improve the wheeled mobile robot performance.

The mixed velocity-force control [10] algorithm implemented chooses one of the wheels as a reference (for example the front wheel). On this reference wheel velocity control is realised using a PID compensator. Modifying the voltage of the motor, the control algorithm minimises as much as possible the difference between the real measured velocity on this wheel and the programmed velocity. It is necessary to note that in this situation the current consumption of this motor is a_1.

Due to fact that the robot movement is a quasi-static process, the traction motor load torque is approximately equal to the internal motor torque. At the same time, the internal torque is proportional to stator current; so it is possible to work directly with currents instead of load torques, achieving simplification in the control system.

In this way, the algorithm controls the load torque of the traction motors of the two different wheels maintaining the optimal distribution of the load torque between three wheels.

It is clear that the best way of torque distribution between the power motors is such distribution when a torque in each wheel is proportional to normal force in this wheel. In this case it is possible to prevent a situation when one wheel starts to slide and other wheels are working far from sliding condition and produce small traction forces.

To distribute torques between the power motors proportionally to normal forces it is necessary to supply such voltages on the second and third power motors, which will provide motor currents according to a formula:

$$\left\{ \begin{aligned} a_2 = a_1 \frac{N_2}{N_1} \\ a_3 = a_1 \frac{N_3}{N_1} \end{aligned} \right\} \qquad (1)$$

where a_i – current value of power motor number i, A;

N_i – normal force applied to the wheel number i, N;

$i = 1..3$.

To demonstrate the effectiveness and applicability of the proposed method, a real time control algorithm was implemented and experimental trials were realised using a prototype (Figure 2) with three independently driven wheels, with one additional DC motor for the steering. Some of the experimental results that will be shown in the report examine the relationship between the velocities and the currents of the traction motors while the robot moves upon flat planes, vertical planes, and planes with irregularities.

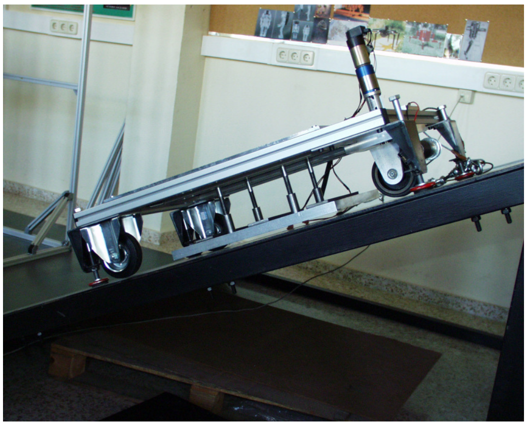

Fig. 2. **Experiments with a mobile robot**

Finally, a comparison between the designed prototype and a conventional mobile robot will be presented. The conventional mobile robot uses a tricycle configuration (with one power motor and one steering motor) and a traditional PID velocity control. The designed prototype proved to have the traction force several times bigger than the conventional tricycle.

Design of an additional device for movement in extreme situations

If a surface is not very complex, a robot can work in the regime described above. On Figure 3 it is shown that if a surface is too complex for movement (sand, snow, obstacles), a situation can occur when all wheels start to slide. At this moment wheels of the robot start to self-excavate the robot.

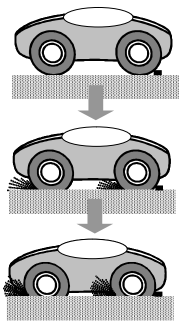

Fig. 3. **Self-excavation of the robot**

To avoid this problem we made a following modification of the robot [11]. On the robot, the axis of the rear wheels was directly connected to the body of the robot and the axis of the front wheel was located on a special mobile element, which is connected to the body of the robot, and can slide forward and back (Figure 4). An additional motor was fixed on the body and was kinematically connected with a mobile element (through a transmission belt-pulley or screw-nut). Each wheel had a blocking device. A special catch with electromagnet or power motors of wheels can be used like blocking devices.

If the robot starts to work in the same mode on a sandy surface, the powered wheel (or wheels) starts to move the under-wheel sand, so that the wheel would move down inside the sand and the robot would not be able to continue moving forward.

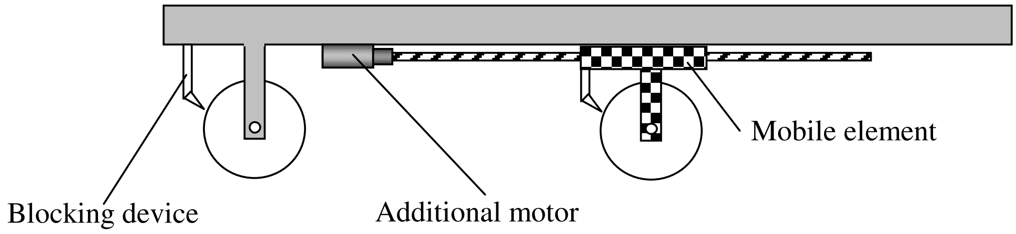

Fig. 4. **Additional DOF on the robot**

For this case the second regime of moving can be used (the power motors are disconnected to prevent self-excavation of wheels). This regime consists of the following steps:

(1) The stopper of the front wheel is disconnected, the stoppers of rear wheels are connected; the additional motor begins to move the mobile element forward together with the front axis and the front wheel; in this step the front wheel makes passive forward rotation; the rear wheels do not move because of stoppers. The motor stops at the moment, when the mobile element arrives into the extreme position.

(2) At this moment, the stoppers of rear wheels are switched off and are now disconnected, and the stopper of the front wheel is connected. The additional motor is trying to move the mobile element back but the mobile element does not execute any movement because of the force of friction between the front wheel and the surface, and because the front wheel is fixed. Consequently, the body of the robot starts to move forward; in this step the rear wheels make passive forward rotation; the additional motor stops at the moment, when the mobile element arrives to the extreme position.

After that the whole process starts again.

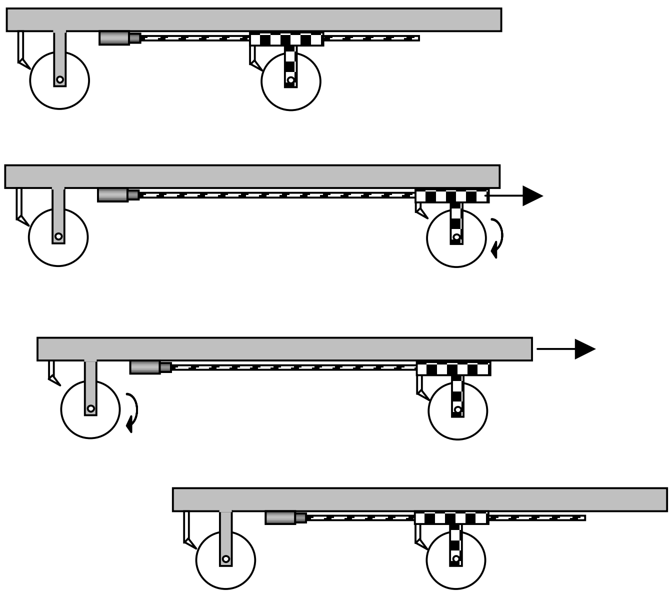

Fig. 5. **Working process (second mode)**

Figure 5 shows the steps of the second regime described above.

Thanks to the stoppers on the rear wheels, during the step 1 these wheels behave together like legs in a walking robot, which can hold the given position on the ground. During this step the front wheel acts as a conventional passive wheel.

In the same way, during the step 2, thanks to the stopper on the front wheel, this wheel behaves as a leg in a walking robot, which can hold the given position on the ground. During the same step, the rear wheels act as conventional passive wheels.

During one full cycle of movement, front and rear wheels are playing consecutively two roles: wheel and leg, conferring to the robot a hybrid robot's typical performing.

Experiments (Figure 6) with such configuration of the robot in very complex road conditions (sand with obstacles) showed that the robot can cross the obstacle and instead of self-excavation of wheels produce sand-self-support. This self-support helps the robot in creating additional traction force and crossing obstacles.

Fig. 5.**Creation of sand-self-support**

Results and discussion

A special design of a robot for rural environment is proposed, inspired by the need to move the robot on the unpaved roads, including sandy, clay, snow-covered roads with roughness and possible obstacles. The robot can act in two modes - continuous motion mode and intermittent motion mode.

The continuous motion mode is a basic mode. At this mode of motion all wheels of the robot are driving wheels and the robot moves like a go-anywhere vehicle. A special control algorithm provides a rational distribution of traction forces between the wheels, including in the case of motion on uneven surfaces. This enables the robot to move on most roads in rural environment.

Nevertheless, there particularly difficult road conditions exist (e.g., movement on sand in the presence of obstacles in front of the robot), when the robot can get stuck. Attempting to continue the movement in this mode will lead only to self-excavation of wheels and the end of the motion of the robot.

To avoid this situation, the second mode of the robot has to be used - the mode of intermittent motion. It is shown that in this mode, the front wheel of the robot and its rear-wheel alternately play the role of fixed legs (like walking robots), and the role of free rolling wheels. In this case, instead of self-excavation of the wheels, a formation of sand self-support is forming, which increases the force pushes and helps to overcome the obstacle.

The tests of the robot showed high efficiency of the robot on soft, sandy soil, where the traditional wheeled robots cannot move because of self-excavation of the wheels.

The elaborated principle of construction of a wheeled robot can be effectively used in rural environment for transportation of goods or as motorized wheelchairs.

Conclusions

1. A special design of a wheeled robot for displacements over uneven terrain (sand, mud and snow) has been developed.
2. The robot can operate in two different modes – in a basic mode of continuous motion with a drive from the motors at all wheels of the robot and in a supplementary intermittent motion mode to prevent self-excavation of the wheels in especially difficult road conditions.
3. Special algorithms have been elaborated to control the robot for both basic and supplementary regimes.
4. Prototypes of the robot have been developed, manufactured and tested. The tests in difficult and very difficult road conditions confirmed that the robot is appropriate to use in rural environment.

Acknowledgments

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