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Sensing Terrain Parameters and the Characteristics of Vehicle-terrain Interaction Using the Locomotion System of a Robot

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1. Introduction

A good perception system is important for a mobile robot that must execute autonomous piloting and navigation in an unknown unstructured environment. Terrain information is needed for path planning, terrain trafficability evaluation, obstacle avoidance and also for automatic locomotion mode control of robots having several modes available. There are two basic principles for the sensing of terrain. The first sensing method is based on touching the ground and the second is based on contactless range measurements. Of course, it is possible to use pre-information that has been catched before the mission started.

With the contactless measuring system, it is possible to model the terrain along a greater distance than sensing by touching the ground, but when operating off-road there are a lot of features that dilute ranging reliability. Vegetation, trees, bush and even snow hinder or prevent scanning real terrain surfaces. Above all, with vision and other range-based systems, it is hard to discover soil characteristics, such as the deformation and compressibility of the soil under pressure and the reactions of soil particles to the horizontal forces, e.g. shear strength or soil strength. Therefore, to get information about soil characteristics, sensing by touching is needed.

The main factors of vehicle-terrain interaction are load-carrying capacity of soil and traction performance of the wheel. Furthermore, geometry of the terrain has a great effect on locomotion. Deformation and compressibility of the soil represent the bearing capacity of the soil. Shear strength of the soil represents the traction performance of the wheel. There are standard methods to measure deformation, compressibility and shear strength of soil, but these methods are not practical for a moving vehicle because they are based on standard devices and procedures requiring in-place measurements (Bekker, 1969 ; Karafiath & Nowatzki, 1978; Wong, 1994).

This chapter describes new real time sensing methods, while driving, for determining terrain geometry parameters such as slope and roughness, and also the characteristics of vehicle-terrain interaction through energy consumption, motion resistance and slippage using the locomotion system as a sensing system so that minimal or no additional sensors are needed. The terrain sensing methods described are generally not dependent on the particulars of the implementation of the locomotion system (such as degrees of freedom or joint and linkage types). The methods have been tested with the WorkPartner service robot that has a multimode locomotion system.

2. Sensing the characteristics of vehicle-terrain interaction

Moving over natural terrain and measuring soil parameters at the same time is difficult (Ojeda et al., 2005). It is really more practical to sense the characteristics of vehicle-terrain interaction, such as the energy consumption and traction or rolling resistance of the wheel, and use them instead of these parameters.

2.1 Sensing load-carrying capacity of soil using energy consumption

Wheel or foot sinkage is a good characteristic to describe load-carrying capacity (Iagnemma et al., 2004), but unfortunately it cannot be measured in a reliable way in a demanding environment. It can be estimated indirectly by using the energy consumption of the wheel or energy consumption of walking. When moving with constant speed, the used energy finally converts to deformation of soil and heating of the wheel. In very soft soil, the wheel also looses energy when bulldozing the ground.

In a fully electrical actuating system, the torque of each wheel can be easily calculated using the current of the electric motor. The power of the wheel is derived from the torque and angular speed of the wheel. The used energy should then be scaled to the traveled distance. In general, the total energy of the propulsion system is used for acceleration of the robot, driving uphill or in some cases pulling a load. In all cases some part of the energy is lost in wheel-soil interaction. To calculate the lost energy correctly, all these essential matters should be considered. Ground slope can be derived from the robot attitude and the wheel positions relative to the robot body. Hence the sum of all the wheels' lost energy in wheel-soil interaction per traveled distance, which can also be called rolling resistance, is

$$F_{roll} = \frac{\sum_{j=1}^{n} E_j}{s} + mg\sin\theta_p - ma_x \, , \tag{1}$$

where E_j is energy of the wheel j, s is traveled distance of the vehicle, m is mass of the vehicle, g is acceleration due to gravity, θ_p is pitch angle of terrain slope, a_x is longitudinal acceleration of the vehicle and n is the number of the wheel. In rolking (Leppänen et al., 1998) or walking locomotion energy consumption can be calculated by considering all joints.

2.2 Motion resistance in static situations

In off-road operation, it can happen that an obstacle or obstacles force the vehicle to stop or the front wheels sink into the soil, thus preventing the vehicle from driving forward. Then the vehicle speed is zero and energy consumption per traveled distance cannot be determined. In this static situation, motion resistance can be estimated by using wheel torque as follows

$$F_{static} = \sum_{j=1}^{n} \frac{\mathrm{T}_j}{r_R} + mg\sin\theta_p \, , \tag{2}$$

where T_j is torque of the wheel j, r_R is rolling radius of the wheel, m is mass of the vehicle, g is acceleration due to gravity and θ_p is pitch angle of terrain slope.

The static motion resistance can be used to indicate a sudden and difficult obstacle, such as a hole in the ground or if the vehicle body gets stuck.

2.3 Energy consumption of a single wheel in wheel-soil interaction

The wheel generates a drawbar force to the robot body in good conditions. In very soft terrain, a single wheel can produce a resisting force with respect to the body, although the wheel still consumes lot of energy in generating wheel torque. This happens especially when a single wheel sinks into the ground and bulldozes soil. If the pulling or resisting force of the wheel can be measured with the help of forces measurement in the suspension system of the wheel, and if the wheel power is known, it is possible to estimate the lost energy in each wheel-soil interaction. The energy that the wheel consumes in wheel-soil interaction per traveled distance is

$$F_{roll\_w} = \frac{E_w}{s} - F_{DP}, \tag{3}$$

where E_w is energy of a wheel, s is traveled distance of the vehicle and F_{DP} is the drawbar pull of the wheel.

In a static situation, when the vehicle speed is zero, the motion resistance of a wheel can be estimated by using the wheel's torque as follows

$$F_{static\_w} = \frac{T_W}{r_W} - F_{DP}, \tag{4}$$

where T is torque of the wheel, r_W is rolling radius of the wheel and F_{DP} is the drawbar pull of the wheel.

The motion resistance of a single wheel can be used to localize the problematic ground area under the vehicle, which enables more sophisticated locomotion control.

2.4 Motion resistance of the transfer leg's wheel in rolking mode

In rolking mode, the transfer leg's wheel drives to the next support position without propelling the robot and lightened. Then the transfer leg's wheel does not strain soil and the real load carrying capacity of soil remains unknown. However, with the unloaded driving wheel, it is possible to recognize very soft soil that resists the driving wheel. In addition, with the unloaded driving wheel, it is possible to sense terrain obstacles that also resist the wheel. In the transfer phase, the wheel is under speed control and the transfer leg moves the wheel to the next position. Thus, the motion resistance of the transfer leg's wheel is a sum of the wheel force generated by wheel torque and the leg pushing force as determined in Equation (4).

2.5 Sensing drawbar force of the wheel in wheeled mode

The traction performance of the wheel is one of the main criteria in the analysis of the vehicle mobility. If the drawbar pull produced by the wheel with respect to the robot's body can be measured directly, it describes wheel-soil interaction. If the motion resistance of the wheel is lower than the generated tractive force, the wheel pulls the robot's body.

Otherwise, the wheel resists the robot. The pulling or resisting force generated by the wheel can be calculated using force measurement in the suspension system of the wheel. In the case of the wheeled leg, the force affecting in the fixing point of the body can be derived using the leg joint's torques.

2.6 Slip of the wheel

In slippery conditions where the friction coefficient between the wheel and the soil is low or the shear strength of the soil is limited, the wheel slips and therefore the traction force is lower. The longitudinal slip of the wheel, when a driving torque is applied, is usually defined by the equation

$$S = \left(\frac{r_R\omega - v}{r_R\omega}\right)*100\%\,, \tag{5}$$

where S is slip, r_R is rolling radius, ω is angular velocity of the wheel and v is forward velocity of the vehicle (Gillespie, 1992; Wong, 2001). It has been observed experimentally that using this kind of slippage value and driving with rubber tires the best traction occurs with a slippage of 15 - 20 % (Wong, 2001).

The angular velocity of the wheel can be measured reliably by an encoder. The speed of the vehicle can be estimated using the average of the wheel speeds so that the wheel that has its speed deviate most from the average of all is not taken into account in speed calculation. Problems, however, occur if all wheels slip at the same time. Then the velocity of the vehicle cannot be determined with pure wheel speed sensor information. In the four-wheel locomotion system, it is possible to use one wheel as a sensor wheel for estimating the vehicle speed. Then a sensor wheel rolls freely and measures vehicle speed and odometry. Unfortunately, the drawbar pull of this sensor wheel is lost, which can be critical in low frictional conditions.

In very slippery conditions, vehicle inertia sensors with GPS (Global Positioning System) navigation can be used for estimating vehicle speed and odometry. Another way is to use a separate sensor wheel in bad conditions. Vision-based sensing methods for estimating the speed of a vehicle are still under research, but might help in the future.

For example, excessive wheel slippage can be used as an indicator that the terrain has become problematic for wheeled driving and a switch of locomotion to rolking could be beneficial.

3. Sensing terrain geometry

A terrain range scanner, based on laser or vision technology, is crucial for autonomous mobile robots, because the terrain information is needed for path planning and obstacle avoidance. Using a vision system or laser-based technology, it is possible to get the geometry of terrain in good environment conditions, but when operating off-road there are a lot of features that dilute ranging reliability. The main emphasis here is put on sensing the geometry of the terrain surface by touching, because the actual terrain surface under snow or vegetation can be detected with the loaded wheel reliably. A negative aspect of the touching method is that it limits the robot's velocity, because it is possible to sense only terrain that is under the robot. Terrain slope and roughness are the main characteristics that express the geometry of terrain.

3.1 Sensing terrain slope

The terrain slope angles, terrain pitch (θ_p) and terrain roll (θ_r), express the inclination of the terrain according to the gravitational vector (g). Terrain slope can be derived from the robot's body inclination and wheel positions utilizing the robot coordinate systems that are shown in Figure 1.

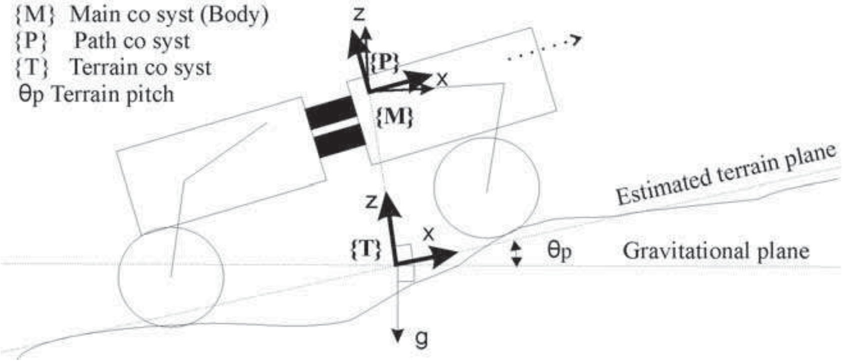


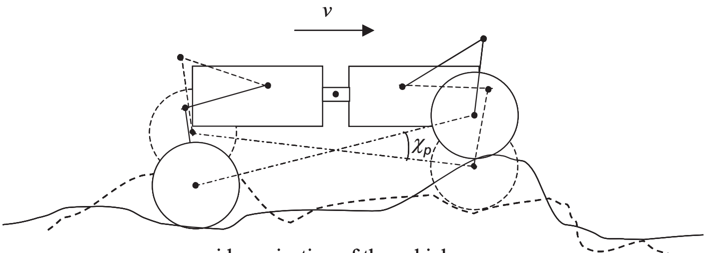
Fig. 1. Relation of the coordinate systems of the wheel-legged robot and terrain pitch.

The estimated terrain plane is derived from the wheel positions in the main coordinate system. It can be obtained by using linear regression in fitting a plane into the set of the wheels' position coordinates. The pose of the main coordinate system with respect to the gravitational vector can be measured by inclination sensors. Using this information, the terrain pitch and roll angles with respect to the gravitational vector can be calculated.

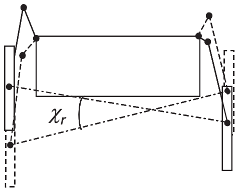
3.2 Sensing terrain roughness

In locomotion studies, the geometry of the terrain surface cannot be divorced from vehicle characteristics, because what is rough for a small vehicle, such as a small conventional car, may be smooth for a large off-road vehicle with large wheels. There is no good and standard way to model terrain roughness, because natural terrain is composed of an unlimited number of features. Typical often-used separate features in modeling terrain are ditch, step, ramp or a separate obstacle with basic parameters, such as height and width. Modeling of the terrain with standard features can be achieved, but collecting enough geometrical information in real operating conditions can be very difficult. When driving at high speed, vibration of the body informs of terrain surface roughness, but it only tells about the ground surface pattern. In addition, soft soil dampens the vibration effectively. At low speed, the suspension system of the vehicle filters the unevenness of terrain.

The wheeled vehicle with a suspension system will align itself according to terrain. If the wheel positions with respect to the vehicle body are known, it is possible to use the sum of the wheel distances to the estimated support plane as an indicator of terrain roughness. Because this terrain roughness indicator does not take the vehicle size into account, another way to estimate terrain roughness is proposed. This method is based on using virtual axles that connect the wheel centers as illustrated in Figure 2.



side projection of the vehicle



front projection of the vehicle

Fig. 2. Terrain roughness indicator based on the virtual axles and their difference angles in the side and front projection.

This terrain roughness indicator takes the vehicle size, i.e. wheelbase and wheel distance, into account automatically. This indicator does not detect vertical surface parts that are problematic for the wheel. On the other hand, if the value of this indicator is high, it is likely that terrain consists of more vertical surface parts that are problematic for the wheel and need more drawbar force. In wheeled mode, there is another limitation using this method for sensing terrain roughness: if the front or back wheels, or even all the wheels, encounter a hump (or ditch) at the same time, the value of this roughness indicator remains small although the terrain will be difficult for the wheel to negotiate.

4. Experimental verification of the sensing methods

The described sensing methods are generally not dependent on the particulars of the implementation of the locomotion system (such as degrees of freedom or joint and linkage types). However, since the methods have been tested with a particular robot with a multimode locomotion system it is necessary to describe the multimode locomotion system and the robot used for testing.

4.1 The multimode locomotion system

The basic idea is to combine the best properties of both of the two main locomotion principles, wheeled and legged locomotion: high-speed locomotion of the wheel and good terrain negotiating capability of legged locomotion. This is achieved with a multimode locomotion system. The minimum requirement for this is that a wheel is attached with a suspension system that has active horizontal (longitudinal) and vertical degrees of freedom.

From here on the wheel suspension is referred to as a “leg” although it does not need to have a leg-like implementation.

The multimode system can then be used for new hybrid modes to help find an optimal solution for greatly varying ground conditions. In hybrid locomotion the wheel and the leg actuators generate the propulsive force simultaneously. It can also be called rolking (rolling-walking), as named in (Leppänen, 1998) or wheel-walking as named in (Kemurdjian, 1990). Rolking resembles walking and works like the following. When a wheeled leg is in the supporting state, the propulsive force is generated by the leg actuators. When the wheeled leg is in the transferring phase, it is not lifted in the air, but lightened and moved along the ground by touching it all the time, while applying a slight forward torque to the wheel. Rolking offers better propulsion in soft soil and good obstacle negotiation.

The locomotion system offers sensor information that is useful for measuring and calculating the quality of the terrain the robot is moving on, and the characteristics of the interaction between the robot and the terrain. This information includes the strain forces affecting each leg and wheel or foot and also the positions of the ankles, or wheel hubs, relative to the robot body.

4.2 The test robot - WorkPartner

One of the more advanced hybrid vehicles to date is the WorkPartner service robot. WorkPartner is a centaur-like service robot with four wheeled legs and a human-like upper body with two hands and a head (see Figure 3).

Fig. 3. The WorkPartner service robot seen here in winter on a test track, negotiating obstacles.

The size of WorkPartner is such that it is suited to co-operating with humans. It weighs about 270 kg. The actuation system is fully electrical. The “muscles” of the legs are identical electric linear actuators that consist of a 250W motor, a reduction gear and a ball screw. The energy system is hybrid, which carries the energy in the form of fuel and transforms it into electrical power for robot actuation. For this, the system includes a combination of a small lightweight combustion engine with generator and batteries.

WorkPartner is built on a mobile platform that consists of four legs equipped with wheels and an active body joint (Halme et al., 1999) shown in Figure 4.

Fig. 4. WorkPartner in an early stage of development, where the structure of the legs and front and rear bodies can be seen.

The wheeled leg consists of a 3-dof mammal-type leg and an active wheel. The rounded profile rubber wheel is designed to have two functions: as a foot in the rolking or walking mode and as a wheel in driving mode.

The locomotion system of WorkPartner allows motion with legs only, with legs and wheels powered at the same time or with wheels only. This enables it to move over different types of terrain with minimum strain to the robot and terrain (Virekoski & Leppänen, 2007) and can sense terrain parameters and the characteristics of vehicle-terrain interaction successfully.

4.3 Sensor system of WorkPartner

The WorkPartner sensor system includes sensors for observing the internal state of the robot and perceiving the outside world. Only the sensors for controlling the locomotion of the robot are described here. A more detailed description of other sensors and sensing algorithms can be found in (Selkäinaho, 2002) and (Halme et al., 2003).

Leg joints angles are measured by potentiometers and encoders that are connected to the leg controller. Inclination of the body is measured using gravity-based inclinometers connected to the middle joint controller that also takes care of the energy system. This sensor information is enough for motion control in most situations, but when force control is needed, force measurement should also be available. Implementing force sensors in every actuator is complicated. Therefore an alternative indirect method of measuring the forces through the driving currents of the joint motors is used. The joint gear reductions are relatively small, which allows a moderate accuracy in force measurements to be achieved this way. Kinematic calculations are then used to calculate the forces in the contact points that the robot has with the environment. This sensor system is then readily available for sensing terrain parameters and the characteristics of vehicle-terrain interaction.

4.4 Energy consumption of WorkPartner

Table I shows the measured energy consumption of WorkPartner in both wheeled and rolking locomotion modes in different terrain conditions. Each terrain type was driven through 3 times and the average is shown. The deviation was ~10% in the worst, softest conditions. The speed value was calculated as an average of the three least slipping wheels, i.e. the wheel that had its speed deviate most from the average of all four was not taken into account in speed (or odometry) calculation. It should also be noted here that the wheels do not slip as freely as in e.g. a car because they are under a speed controlled mode. During the tests for table I it was also visually confirmed that excess slippage did not occur and the robot advanced at all times. If the slippage should be excessive, and by multiple wheels, it would hamper the measurements of real vehicle speed and odometry, and then an external measuring device, e.g. a distance/speed wheel would be needed.

Locomotion mode	Speed [cm/s]	Energy consumption [J/m]	Terrain
wheeled mode	50	130 (wheels only)	Flat hard
wheeled mode	50	600 (wheels only)	Soft sand
wheeled mode	50	600 (wheels only)	Soft snow 15 cm, without ice layer
wheeled mode	50	900 (wheels only)	Soft snow 22 cm, without ice layer
rolking, crawling gait	2	2800	Flat hard
rolking, crawling gait	2	4500	Soft snow, 25 cm
rolking, trot gait	4	3700	Flat hard
rolking, worm gait	4	4000	Flat hard

Table 1. Energy consumption of WorkPartner. Losses in the gears and the linear actuators are included in energy consumption values. See text for more details about speed and energy measurements.

The energy consumption of rolking as well as walking will increase in softer soil. Slip of the support legs doesn’t only affect the speed of the robot, but also the energy consumption, as shown in Figure 5. Note that energy consumption of rolking is generally higher than wheel motion, but in some terrain conditions, like deep snow, it is the only way to move.

In this experiment, the robot climbed up a slippery 18 ^{o} slope successfully. Slipping of the support legs causes more internal forces in the robot (Lehtinen, 1994), which results in increasing energy consumption. When the robot succeeded to move from the slippery slope to more frictional and flat terrain, the energy consumption decreased. Energy consumption is a good indication of the softness of the soil.

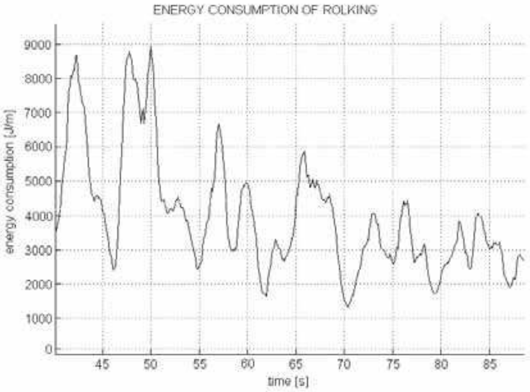


Fig. 5. During this test run the robot climbs up, rolking, a slippery 18 ° slope that causes slip of the support legs. Energy consumption decreases when the robot arrives on flat and level ground.

4.5 Energy consumption and slip of a single wheel in wheel-soil interaction

The energy consumption of a wheel per traveled distance increases if the wheel drives on soft soil or slips a lot under low-frictional condition. To illustrate energy consumption and slip, WorkPartner climbed a slippery 18 ° slope; test results of this climb can be seen in Figure 6. The rear left wheel started to slip and the speed of the robot decreased. In general, all slipping wastes energy.

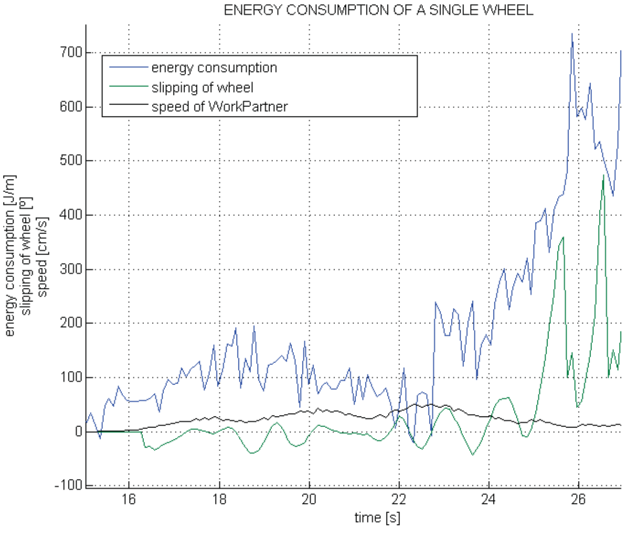


Fig. 6. WorkPartner tried to climb a slippery 18 ° slope with wheels. The rear left wheel started to slip, which also increased the energy consumption of the wheel per traveled distance.

4.6 Motion resistance of the transfer leg's wheel in rolking mode

Terrain trafficability can be estimated with motion resistance of a transfer leg's wheel. For example, when the depth of snow decreases, so does the motion resistance of the transfer leg's wheel also, as can be seen in Figure 7. At the end of this test, WorkPartner moved on firm ground during 214 – 235 seconds, when the average motion resistance of the transfer leg's wheel was about 80 N. The load of the transfer leg's wheel stays almost constant, because the load of WorkPartner is divided so that the support legs carry about 85% of the robot's weight and the transfer legs only about 15 % (Virekoski & Leppänen, 2007).

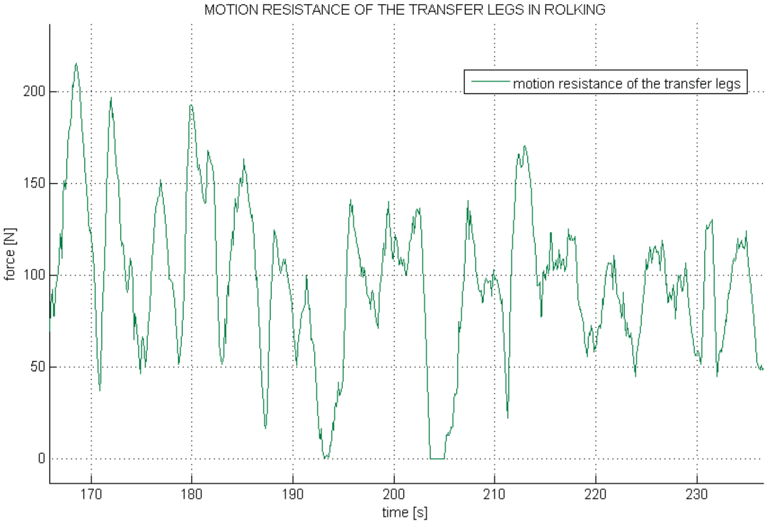


Fig. 7. WorkPartner rolked from soft snow to firm ground. Motion resistance of the transfer legs decreased.

4.7 Sensing terrain slope and roughness

To demonstrate the terrain slope and roughness sensing principles, , WorkPartner climbed over a 30 cm high and 140 cm long ramp with the left side wheels; the results are shown at the bottom of Figure 8, while the ramp is shown at the top. The ramp is so short that the left front wheel climbed first up then down and the robot was level for a short time before the rear wheel did the same. The wheels were in the nominal positions so that the wheel base was 1,45 m and sideways distance between the wheels was 1,0 m. If a wheel of WorkPartner is on an obstacle with a height of the radius if the wheel (0,23 m) and the other wheels are in the nominal positions, the roughness is about 22 °. If the opposite corner wheels are on the same size obstacle (0,23 m), then the roughness will double (44 °). In wheeled mode, there is a limitation using this method for sensing terrain roughness: if the front or back wheels, or even all the wheels, encounter a hump (or ditch) at the same time, the value of this roughness indicator remains small although the terrain will be difficult for the wheel to negotiate. In rolking, this kind of limitation only exists when using a worm-type gait in which each pair of wheels in the frontal plane moves only when the other one is firmly braked to the ground.

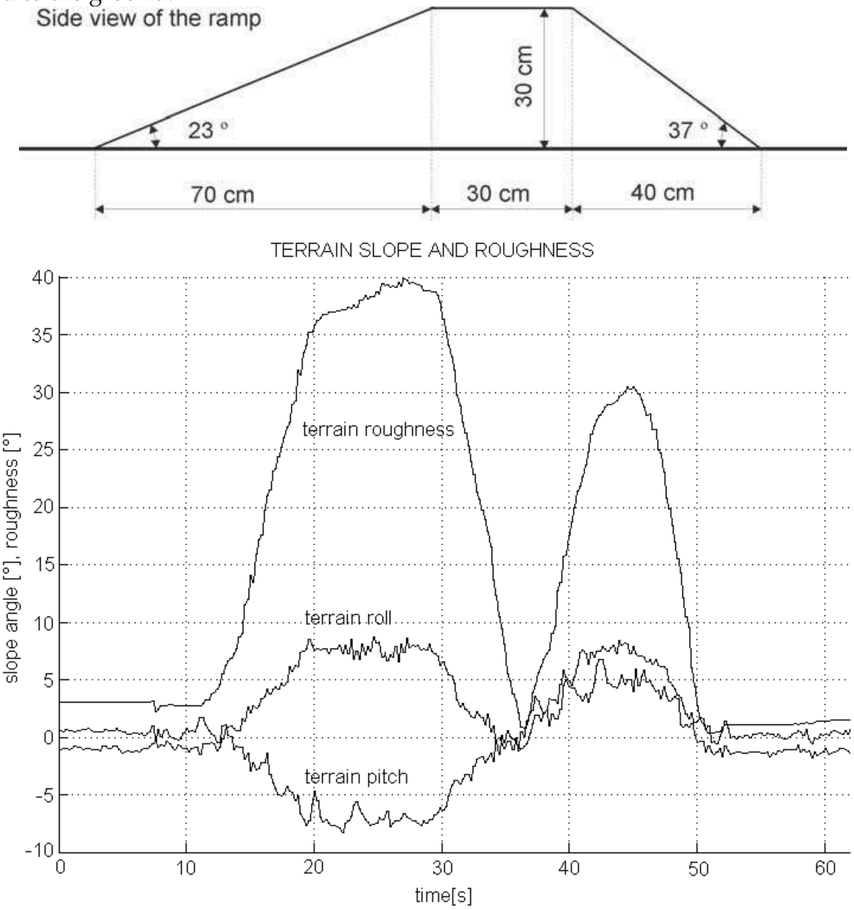


Fig. 8. Terrain slope and roughness. WorkPartner drives over a 30 cm high and 140 cm long ramp with the left wheels. This is a test to demonstrate the terrain geometry parameters only, and the consistency of the driving speed or other parameters is not essential here. The first peak occurs when the front wheel is on top of the ramp (x = 20 - 30 s) and the second with the rear wheel (x = 40 - 50 s). The rear wheel peak is lower because the robot's middle joint is asymmetric and flexes more to the other diagonal.

The roughness sensing method is also valid in rolking mode. A test with WorkPartner rolking over logs, as illustrated in Figure 3, shows that the calculated roughness clearly indicates when the individual front legs go over the log one by one. The result is shown in Figure 9.

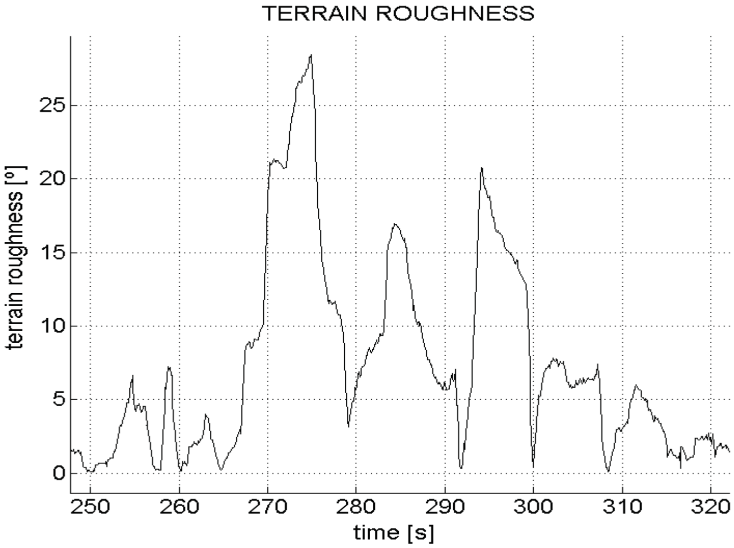


Fig. 9. WorkPartner is rolking over a wooden log, front wheels crossing the obstacle. Terrain roughness is significantly greater when a wheel is on a log. The log is not perpendicular to the driving direction and therefore here the right front wheel climbs on the log first (peak at x = 275) and comes down only at x = 290. The dip at x = ~279 is caused by the left wheel trying to climb the log but slipping back (x = 284). The left wheel comes on top of the log at x = 294.

5. Conclusion

The developed real time touch-based sensing methods for determining terrain geometry parameters such as slope and roughness, and also the characteristics of vehicle-terrain interaction through energy consumption, motion resistance and slippage are based on using the locomotion system as a sensing system. The developed terrain sensing methods can be used for mapping, path planning, terrain trafficability evaluation, obstacle detection and avoidance. These sensing methods have already been applied successfully for determining suitable modes of locomotion automatically (Leppänen, 2007). The automatic locomotion mode control uses a mode that is optimal for current terrain.

Future development should focus on combining these touch-based methods with vision and ranging. Then the robot could learn to associate image information of the terrain to the touch-based information, and then use vision to get more accurate knowledge of the terrain from afar.

6. Reference

Bekker, M. G. (1969). Introduction to terrain-vehicle systems. The University of Michigan Press. U.S.A.

Gillespie, D. G. (1992). Fundamentals of Vehicle Dynamics. Society of Automotive Engineers, Inc. U.S.A.

Halme, A.; Leppänen, I. & Salmi, S. (1999). Development of WorkPartner-robot - design of actuating and motion control system. 2nd International Conference on Climbing and Walking Robots, London, Professional Engineering Publishing Ltd, pp. 657-665.

Halme, A.; Leppänen, I.; Suomela, J.; Ylönen, S. & Kettunen, I. (2003). WorkPartner: Interactive Human-like Service Robot for Outdoor Applications. The International Journal of Robotics Research, Vol. 22, No. 7-8, pp. 627-640.

Iagnemma, K.; Kang, S.; Shibly, H. & Dubosky, S. (2004). Online terrain parameter estimation for wheeled mobile robots with application to planetary rovers. IEEE Transactions on robotics, Vol.20, No.5, pp. 921-927.

Karafiath, L. & Nowatzki, E. A. (1978). Soil mechanics for off-road vehicle engineering. Trans Tech Publications, Series on rock and soil mechanics Vol.2, No. 5.

Kemurdjian, A. L. (1990). From the Moon Rover to the Mars Rover. The Planetary Report, Vol. X, Num. 4, pp. 4-11.

Lehtinen, H. (1994). Force based motion control of a walking machine. Ph.D Dissertation, Helsinki University of Technology, 1994.

Leppänen, I.; Salmi, S. & Halme, A. (1998). WorkPartner, HUT Automation’s new hybrid walking machine. CLAWAR’98 First international symposium, Brussels, Belgium, 26-28 Nov.

Leppänen, I. (2007). Automatic locomotion mode control of wheel-legged robots. PhD dissertation, 105 p, Helsinki University of Technology.

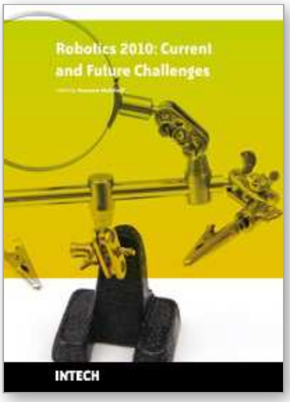
Ojeda, L.; Borenstein, J. & Witus, G. (2005). Terrain trafficability characterization with a mobile robot. Proceedings of the SPIE Defense and Security Conference, Unmanned Ground Vehicle Technology, pp. 1-9.

Selkäinaho, J. (2002). Adaptive autonomous navigation of mobile robots in unknown environments. PhD dissertation, 88 p, Helsinki University of Technology, 2002.

Virekoski, P. & Leppänen, I. (2007). Terrain-adaptive Locomotion of a Wheel-Legged Service Robot Using Actuator-based Force Measurements. CLAWAR’2007 10th International Conference on Climbing and Walking Robots and the Supporting Technologies for Mobile Machines, Singapore, 16-18 July.

Wong, J. Y. (1994). Terramechanics – Its present and future. Proceedings of 6th European Conference of the International Society of Terrain-Vehicle Systems, Vienna, Austria, pp.1-21.

Wong, J. Y. (2001). Theory of ground vehicles - 3rd ed., 528 p. New York, Wiley.



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Without a doubt, robotics has made an incredible progress over the last decades. The vision of developing, designing and creating technical systems that help humans to achieve hard and complex tasks, has intelligently led to an incredible variety of solutions. There are barely technical fields that could exhibit more interdisciplinary interconnections like robotics. This fact is generated by highly complex challenges imposed by robotic systems, especially the requirement on intelligent and autonomous operation. This book tries to give an insight into the evolutionary process that takes place in robotics. It provides articles covering a wide range of this exciting area. The progress of technical challenges and concepts may illuminate the relationship between developments that seem to be completely different at first sight. The robotics remains an exciting scientific and engineering field. The community looks optimistically ahead and also looks forward for the future challenges and new development.

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