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TRACTION CHARACTERIZATION IN THE ROBOCUP MIDDLE SIZE LEAGUE

ABSTRACT
In this work the problem of traction of mobile wheeled robots for the particular case of Robocup MSL league was analyzed. In particular the slip occurrence in differential drive DC electrical powered mobile robots was studied. Traction loss was characterized for the set of possible game events ranging from excessive acceleration, centripetal force effects, to collisions (either to fixed obstacles or by external players). The traction analysis was performed with measurements of electrical current on each motor and odometry and inertial data. An approach to overall traction control relying in electrical current data coupled with motion data, is envisioned. This approach does not depend on apriori knowledge of the operating surface or robot motor model.

I. INTRODUCTION
With the field size growth in Robocup MSL some additional requirements to perception and traction control are imposed. In the context of current trends to increase game dynamics, the traction control issue takes an important role. Minimization of robot slippage allows greater performance levels in actuation and improves odometric information.

This paper has pursued the traction characterization of a MSL ISePorto robot through experimentation and in-depth analysis of data measured in a specialized testbed like the MSL scenario. Traction loss was characterized for the set of possible game events ranging from excessive acceleration, centripetal force effects, to collisions (either to fixed obstacles or by external players).

The used robots have conventional wheels in a differential traction arrangement with electrical DC motors. The traction study for this traction configuration, used in the ISePorto robots, has the advantage (in comparison with the more popular omnidirectional wheel MSL robots) of beeing used in many other land based robots (with conventional wheels) namely in outdoor terrains.

This study allows the understanding of the phenomenon associated with the traction process and provides insights to the envision of a traction control architecture and the development of a traction control system. Although, the studied scenario was the Robocup MSL, several traction situations are common to other scenarios, allowing the applications of the resulting system to applications like outdoor vehicles, marine robotics, Segways-like vehicles.

The paper is organized as follows. Section 2 presents the traction control state of art with the different approaches and developments. Section 3 will focuses in the traction concepts that will be required to the traction problems characterization presented in section 4. Section 5 introduces the traction system architecture that will be implemented focusing in communications and hardware issues. The paper concludes with a short discussion of the results obtained and further topics that will be object of study.

II. STATE OF THE ART
Early studies in autonomous vehicle motion control relied only in kinematic models [3]. With the development of new sensors allowing an better world perception, motion improvement was achievable [5]. However part of this work focused in motion dynamics study for path tracking. Other line of development relied in the computing of suitable trajectories in the face of under road holding constraints and varying terrain topography [4].

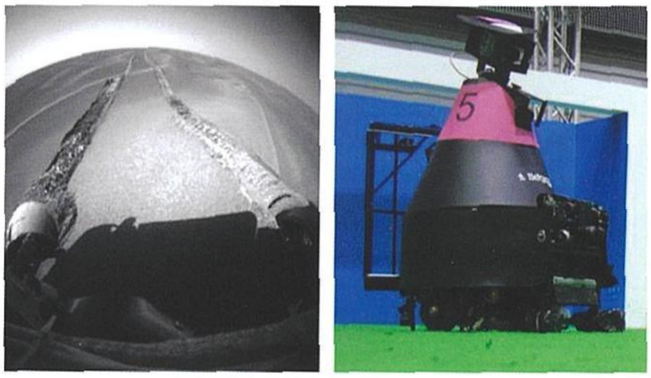

Figure 1 · Road holding constraints and Middle Size League environment.

Terrain (irregularity) poses additional problems in autonomous vehicles subject to dynamic conditions. This can occur due to trajectory dynamics (induced moments and forces) or by variation in surface-wheel contact properties (due to terrain unevenness). Stringent performance requirements coupled with aforementioned traction problems introduce motion degradation capability and slippage. Thus, avoiding slippage conditions while preserving as much as possible motion within required performance is a necessary step. When unavoidable, traction loss must be dealt appropriately either by relaxing motion requirements or adapting motion planning strategy [1][3].

Electric vehicles have been a major line of study due to energy and environmental issues. In terms of traction control, electric vehicles presents a quick and precise torque generation [1] and a low cost and a relative easy controller design. In terms of response, an electric motor has a torque response time less than 10ms opposed to the common internal combustion engines that presents 200ms mainly due to the existence of mechanical systems such as the throttle actuator. In terms of cost, electric vehicle control can berealized only by software and a relative easy controller design because

torque is proportional to the electric motor current.
To the majority of the authors the objective is to reduce the slip rate between the surface and the wheels allowing minimization of power consumption, maximization of the stability, controllability and safety of the vehicle.
With the objective of reduce the slip and improve the adhesion performance for any wheels of surface conditions, many technologies are developed such as optimal slip ratio control[1], Model Following Control (MFC)[1], current disturbance observer, sliding mode measurement feedback control[7], slip ratio fuzzy control, slip controllers based on disturbance observer[9], back-EMF motor control[8] and road conditions estimator[6]. In all control algorithms presented, the wheel speed and vehicle speed are needed with the back-EMF exception that present as a requirement the motor intrinsic parameters.

III. TRACTION

The traction control main goal is to suppress the wheel slip in situations of dynamics changes, surface-wheel variation or other external perturbations. As a result, motion control performance is improved. In the robot motion we should consider two forces. The longitudinal force and the lateral force are strongly depend on the slip ratio. The primary force of interest in studies of vehicle traction is the longitudinal force Fd (see figure 2), which is present in the vehicle motion through all the contact point between the surface and the wheels. The friction force is proportional to the normal force N in the contact point and is consequence of the relative difference between the robot velocity and the wheel velocity, and can be empirically determined by the friction characteristic in terms of wheel slip and surface.

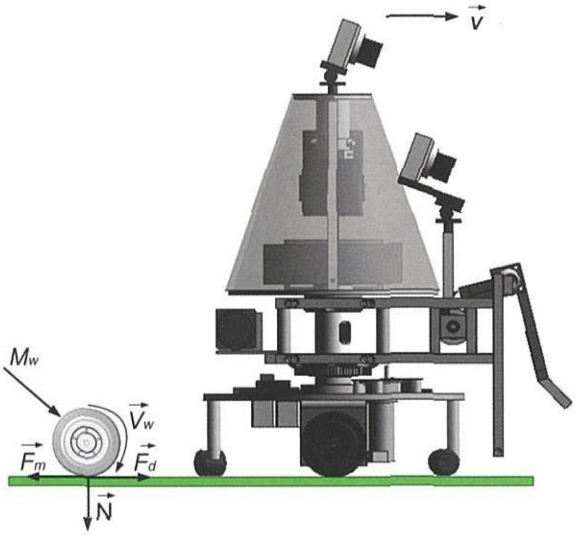

Figure 2 · Forces applied to the ISePorto Player.

A. Wheel Slip

The longitudinal friction force F_d is a consequence of the relative difference between the robot speed and the wheel speed, which is given by $V_w = w_r$.

$$\lambda = \frac{V_w - V}{V_w} \tag{1}$$

$$(F_m - F_d)\frac{1}{M_w s} = V_w \tag{2}$$

and

$$F_d \frac{1}{Ms} = V \tag{3}$$

where, F_m is the motor force, F_d the friction force, M_w the wheel inertia and M the vehicle weight.

B. Friction force and Wheel/Surface interface

Friction force is the tangential reaction force between two surfaces in contact. Physically these reaction forces are the results of many different mechanisms, which depend on contact geometry and topology, displacement and velocity of the robot, properties of the wheels and the surface field. In the figure 3 is possible to observe the friction force value that the robot present in each motion moment. The friction force value present the biggest value when starts the movement and becomes smaller when the robot is rolling. If the friction force presents low values in the acceleration process it means that the robot is slipping. In this situation the robot is making more torque of what is capable to transform in real motion.

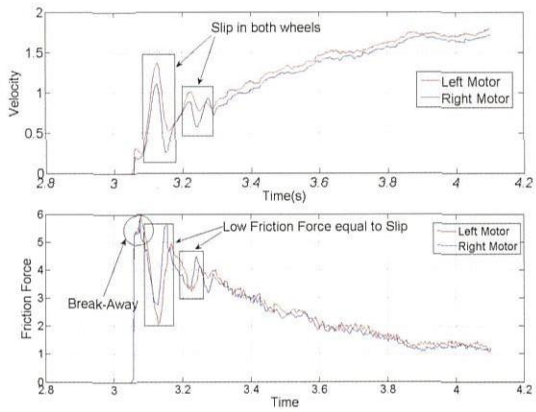

Figure 3 · Friction force.

$$F_d = N\mu_\lambda \tag{4}$$

C. Break-away force

The force required to overcome the static friction and initiate motion in the robot is called break-away force. This break-away force is given by the peak seen in figure 4. The maximum friction force typically occurs at a small displacement from the start point and this value depends on the rate of increase torque applied by the DC motors.

$$\mu = \frac{M}{N}\frac{dV}{dt} \tag{5}$$

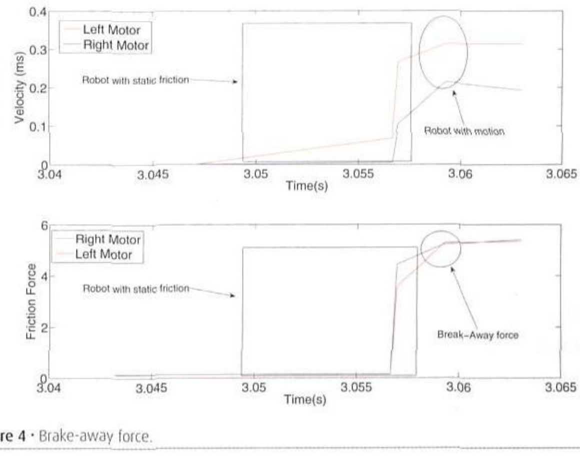

Figure 4 · Brake-away force.

and

$$F_m = K_m I_{motor} \qquad (6)$$

where K_m represent the intrinsic motor parameter and I_{motor} the motor current.

$$\mu = \frac{1}{F_n}(F_m - M_w \frac{dV_w}{dt}) \qquad (7)$$

Based in the equation 6 and 7 the friction force between the contact surface and the wheel is given by

$$F_d = (K_m I_{motor} - M_w \frac{dV_w}{dt}) \qquad (8)$$

IV. TRACTION ISSUES IN MIDDLE SIZE LEAGUE

In a Middle Size game the robots are exposed to dynamic variations of the adherence [2] values, between the surface of the middle size field and the wheels caused by events like pushing, blocked, collisions and crossing the lines of the field. All these perturbations can be observed in the current and velocity value in each wheel.

The tests were realized using a ISePorto Team Robot in a middle size field and all the motor control nodes (DATCOS) were connect to a CAN bus with a baudrate of 1Mbit. The DATCOS performed the current and odometry acquisition with a sample time of 1kHz. The electrical current acquisition was made with a 12bit A/D converter and odometry with a quadrature decoder, giving 5000 ticks per wheel turn. The current and the odometry were filtered with a Equiripple FIR filter of order 4. The values applied to the filter were calculated with the Remez Exchange algorithm.

A. Acceleration

In the figure 5 it's possible to observe the instant when the slip occurred as well as its period, during an acceleration process. Additionally, some loosing/recovering traction cycles can be observed during a period of mode than 250ms. The slip is characterized by an instant of low current and high velocity.

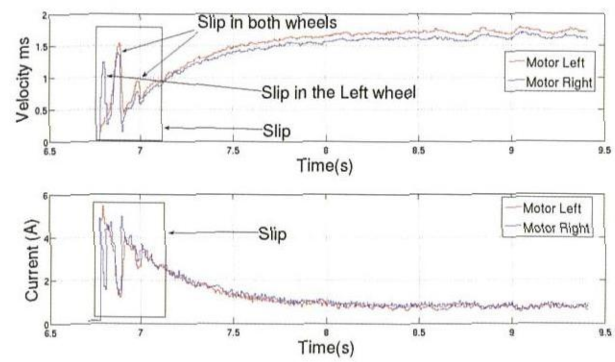

Figure 5 · Slip occurrence in acceleration.

B. Blocking

Blocking occurrence is characterized by a variation in the adherence causing slipping (See figure 6).

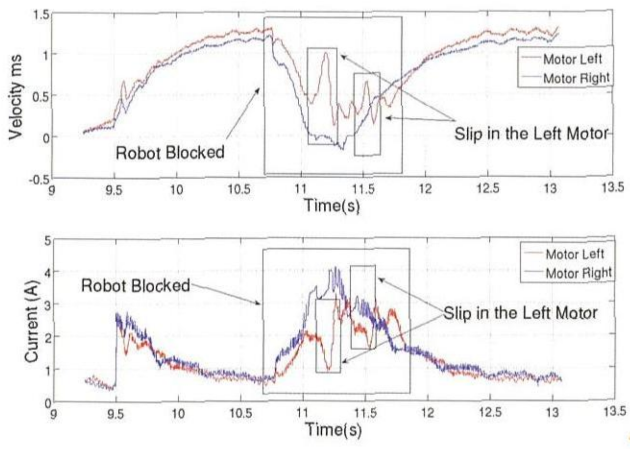

Figure 6 · Blocking caused by robot or obstacle.

C. Pushing

Pushing presents a measured velocity value greater than the reference applied by the application and low current in relation to the expected velocity (See figure 7).

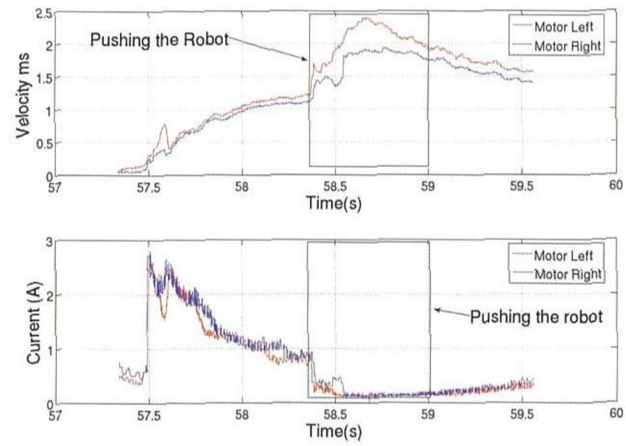

Figure 7 · Pushing by another robot

D. Motion reversal

Motion reversal is a goalkeeper frequent movement (as it moves mainly in both directions in a small area) and without traction control one observe that takes 2s to reverse the motion and recover traction again (See figure 8). This delay makes the goalkeeper vulnerable to the goal possibility.

E. Braking process

In this experiment, a PWM reference degree was applied from maximum value to zero. The braking process in the ISePorto robot can be observed in the figure 9. Without traction control system the robot takes 600ms to stop. This is caused by the robots low adherence between the field surface and the wheels. With the traction control system it will be possible to reduce the slipping period, improving the actuation as well as the localization and navigation quality.

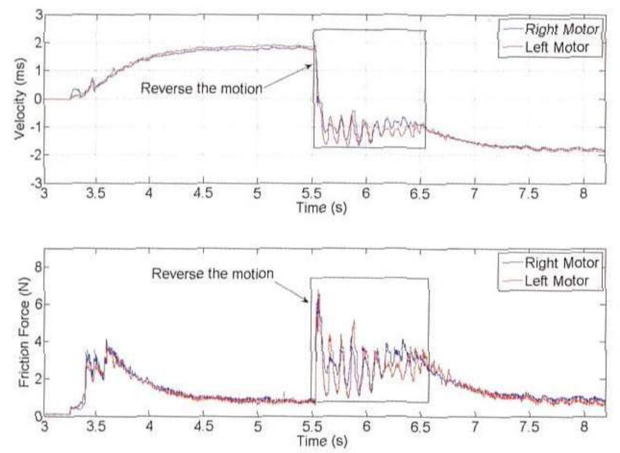

Figure 8 · Reverse the goalkeeper motion.

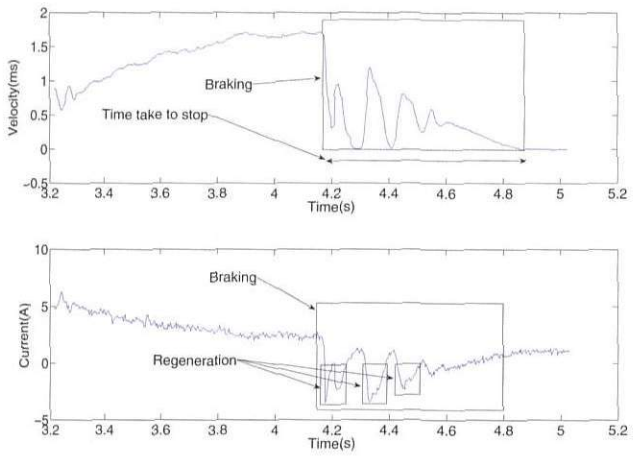

Figure 9 · Braking process in ISeporto Robot.

F. Collision

1) Lateral collision with a moving robot: The lateral collision presents two different behaviors (See figure 10).

The robot can present a lateral force that will influence the motion or can present the handspike occurrence that will result in one wheel that lose contact with the field and the other will have an friction force increase.

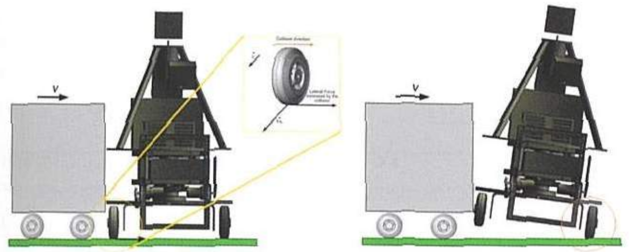

Figure 10 · Collision with lateral force occurrence and collision with handspike occurrence.

***2) Collision with fixed landmark*:** In the collision with a fixed landmark the robot will present low velocity or zero depending the robot position in relation to the landmark. (See figure 13). The current increases and keeps a higher value.

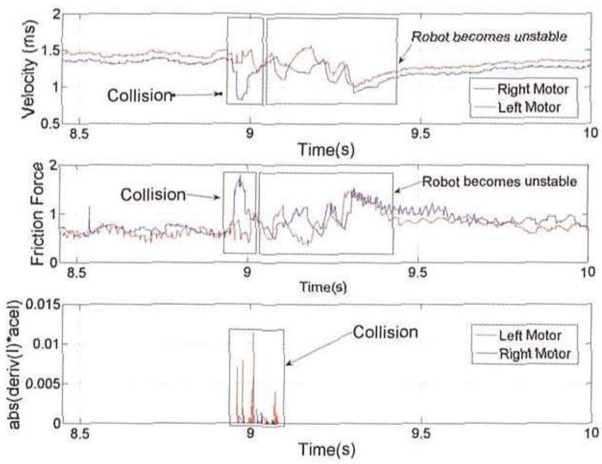

Figure 11 · Right-side collision caused by a lateral crash.

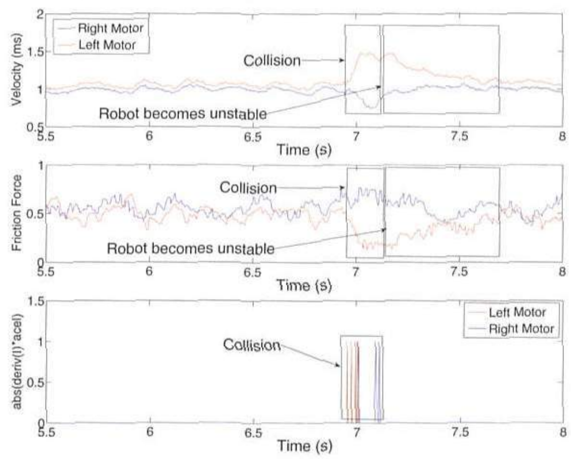

Figure 12 · Left-side collision with handspike occurrence.

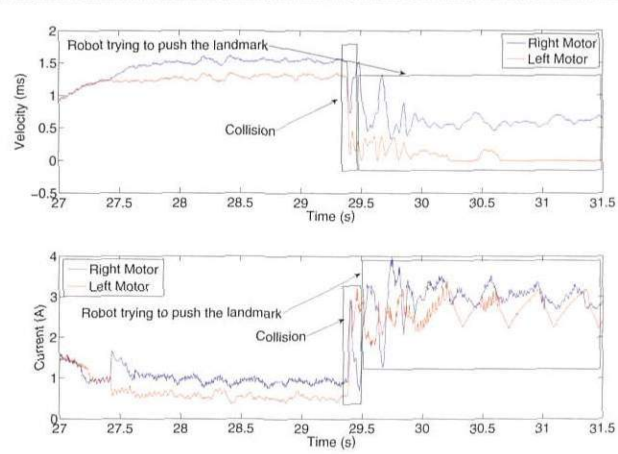

Figure 13 · Collision with a landmark.

In the previous experiments a goal was used and after the collision the robot turned left. This can be observed in the figure 13 because the right wheel keeps with low velocity and the left wheel is stuck.

***3) Collision with still robot*:** In collision with a still robot is different from a collision with a landmark because if the robot is able to win the inertia imposed by the other robot. A slower velocity increase and a slower current decrease will occur. This doesn't occur if the the collision is against a fixed obstacle (See figure 14).

The test presented in the figure 14 was performed with two robots with different weights. The still robot with 40kg and the collision causing robot with 20kg.

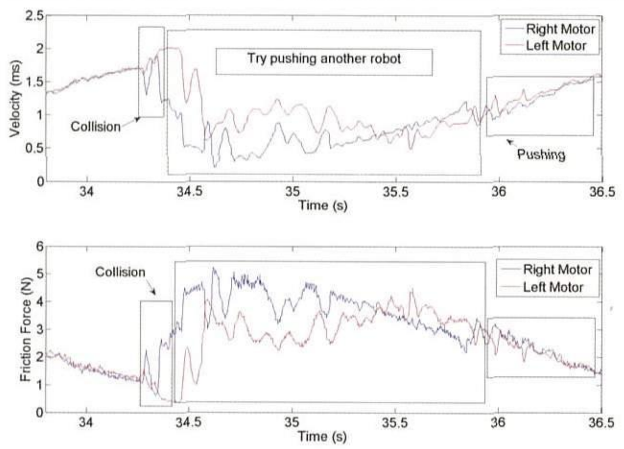

Figure 14 · Collision with a still robot.

G. Wheel without contact with the field

During a middle size game it's usual for the ISePorto robot and the opponent to become stuck and one (or even both) wheel loses contact with the ground (see figure 15).

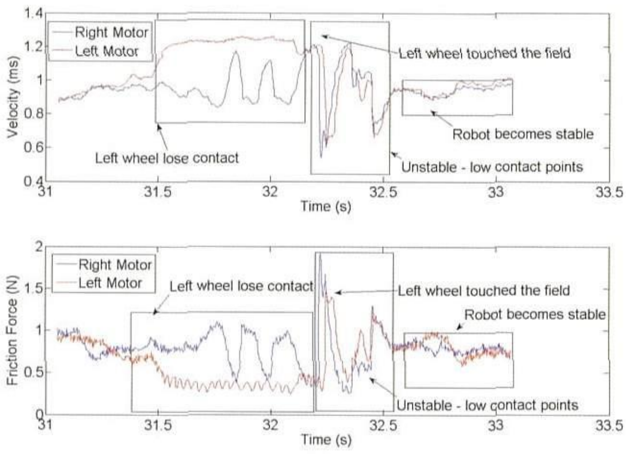

Figure 15 · Left wheel lose contact with the field.

If undetected, this induces relevant errors in the navigation system (through the odometry) and since higher level control keeps wheel reference signals, when the wheel regains traction the robot suffers a sudden unexpected movement. This will cause degradation in the localization of the robot in the field (mainly in short term heading estimation).

H. Slip over the field line marks

The slip over a field line mark it's only possible to observe when the robot is an acceleration/braking process. If the robot is with a stable dynamic motion, the disturbance caused by the lines is not detected (See figure 16).

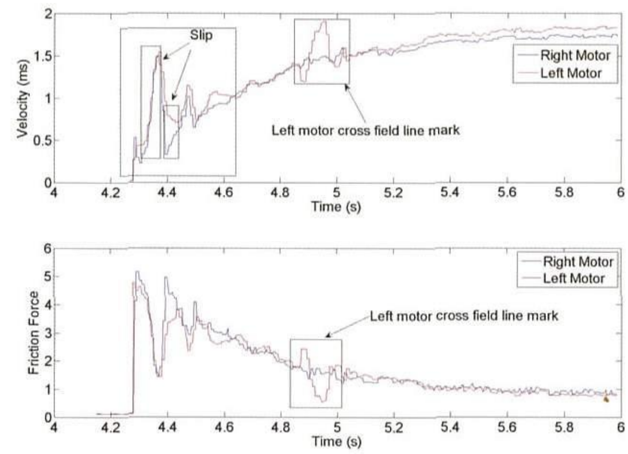

Figure 16 · Left motor cross the field line mark.

I. Unevenness of ground field

The figure 17 depicts a problem that occurred in almost all middle size field area due to degradation during a game.

In previous figure 18 the instant when left wheel crossed a bump in the ground is presented. This perturbation will cause motion degradation that will influence the path defined by the higher level control application.

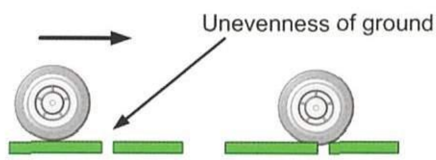

Figure 17 · Ground unevenness field.

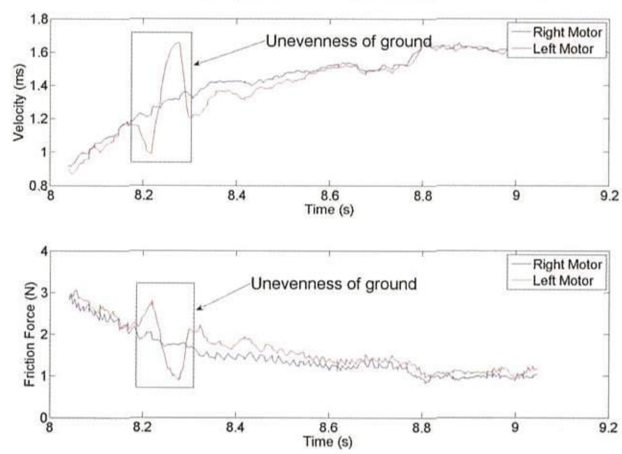

Figure 18 · Ground unevenness field in the left wheel.

J. Traction cases

In the table I, the velocity and friction force detection conditions for the tested traction situations are presented.

Situations	Velocity(ms)	Friction Force(N)
Game		
Acceleration	↑↓ commutations	↑↓ commutations
Blocked	↑↓ commutations	↑
Pushing	greater than reference	↓
Reverse	↑↓ commutations	↑↓ commutations
Braking	↑↓ commutations	regeneration
Wheel without contact	↗	↘
Collision		
Moving robot	↘	↗
Still robot	↘ until stop	↗
Landmark	↘ then ↗ slowly	↗ then ↘ slowly
Lateral (collision side)	↓	↑
Lateral (opposite side)	⟶	⟶
Handspike (collision side)	↑	↓
Handspike (opposite side)	↓	↑
Field		
Cross line mark	↗↘ transition	↗↘ transition
Unevenness ground field	↘↗ transition	↘↗ transition

Table 1 · Detection conditions.

V. ISEPORTO TRACTION CONTROL

A. Traction System Architecture

This traction system is characterized by the capability of having two levels of action. The low level has a responsibly of reduce the occurrence of slip, optimize the torque applied to the motor and send via CAN all the information, continuous values and discreet events, that allow the high level control maneuvers to deal and adapt to the detected event.

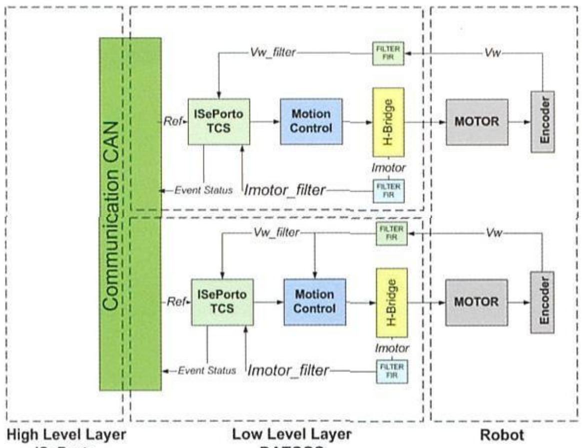

Figure 19 · Traction System Architecture.

If we are capable of understanding the problems, then it will be possible to correct and adapt the path.

B. Traction Control Hardware

The development of new power drives and motion controllers was motivated by the requirement of improving the traction control and the overall robot reliability.

The new axis control node DATCOS (Distributed Active Traction Control System), based on hybrid DSP with CAN interface (see figure 20), allows the reduction of the number of cables, providing torque measurements for traction control, is small sized, low powered, and provides computational capabilities supporting relatively sophisticated control algorithms such as slip, velocity and traction/force.

Figure 20 · Axis control node DATCOS.

C. DATCOS communication CAN

In the majority application that use a distributed architecture with communication CAN all the slave nodes present a fixed send and receive ID or use a dip-switch to configure the ID values.In our application we will present an approach capable of define and configured all the slaves nodes without the previous knowledge. Each DATCOS is capable to be reconfigured in runtime.

VI. CONCLUSION AND FUTURE WORK

The problem of traction of mobile wheeled robots in the Robocup MSL league scenario was analyzed. In particular the slip occurrence in differential drive DC electrical powered mobile robots was studied. Traction control problems in this scenario have a much wider applicability in mobile robotics. Traction loss was characterized for the set of possible game events ranging from excessive acceleration, centripetal force effects, to collisions (either to fixed obstacles or by external players).

The analysis was performed with measurements of electrical current and odometry on each motor with the distributed local control axis/power system (DATCOS).

An approach to overall traction control relying in electrical current data coupled with motion data, is envisioned. This approach does not depend on apriori knowledge of the operating surface or robot motor model. In addition traction control is to be achieved in real time and in distributed form.

The overall motion control infrastructure, already implemented and tested in Robocup competitions allows local slip reduction (by detecting discrepancies in current and motor velocity and reducing reference) and relays to higher hierarchical levels information necessary to replanning.

Local slip control is currently implemented and must be validated and tested in operational conditions.

Higher level response to drastic traction problems must be developed. Robocup competitions will present a relevant scenario for these validation tests.

This work is also to be extended to other robotic motion control applications. In particular to marine robotics, preventing effects such as cavitation, controlling active thrust and minimize thrust reduction due to propeller axial flow.

VII. ACKNOWLEDGMENTS

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