REAL CASES MOTORCYCLE AND RIDER RACE DATA INVESTIGATION: FALL BEHAVIOR ANALYSIS

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ABSTRACT

The need for more safety is beginning to be perceived also in the motorcycle race context, and the demand for more protective motorcycle garments is becoming more challenging. In this scenario DAINESE is working together with some racing teams for investigating new solutions to improve rider safety.
In this paper, dynamical measurements of several motorcycle crashes, recorded both on the rider and the motorcycle, will be presented and analyzed. General tendencies among the different cases and repeatability have been investigated.
The available data was collected during the 2006 MotoGp Championship, which proven to be a perfect scenario for acquiring limit-condition-driving data, and a challenging environment for testing innovative safety devices.
Although focused on the race competitions, this study should also be useful in the future for developing more general purpose rider protection systems.

INTRODUCTION

Predominantly developed for cars airbag technology is still in its first stages with regards to motorcycles. Nevertheless motorcyclists, especially on tracks, are likely to experience falls due to front slippage, rear slippage or high-side phenomena. The dynamic behavior of the motorcycle-rider system during falls is very complex, and the development of a proper rider protection system is to be considered a challenge. The possibility of utilizing the airbag technology also on motorcycles is promising, however to achieve this task numerous fall samples are needed to understand the phenomena.
In this paper example of data recorded during real race falls are reported. A first analysis of these data have been carried out in order to understand what happens during a crash. Several crash simulations in different computing environments [1] and real fall analysis [2] showed some guidelines in this kind of investigations. To analyze repeatability and general tendencies in race crash phenomena a campaign to collect dynamic bike-rider system data has been carried out by DAINESE during 2006 MotoGp World Championship.

DATA COLLECTION

Thanks to the cooperation of some MotoGp racing teams and some of their riders a proper data acquisition apparatus have been installed on some rider-bike system. This led to the possibility to compare actively motorcycle and rider data with the need to place two recording systems on each motorcycle–rider assembly.
This approach has been followed because it is very difficult to understand the dynamic behaviour of a rider without the possibility of analyzing also the motorcycle data. The systems utilized for acquiring the data were 2D data-recording units specifically designed for this task. The assembly is composed of an inertial platform with three accelerometers and three gyrometers, a GPS unit able to record both speed and bank angle.

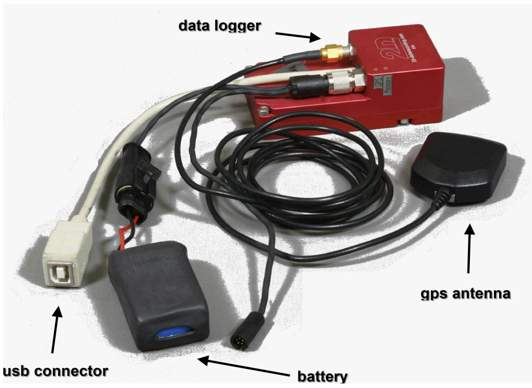

Figure 1. Recording apparatus designed by 2D.

The apparatus is designed to respect the requirements of the race context: it is lightweight, small, very robust. An other big advantage offered, is the widespread diffusion of the 2D software that permitted to share the acquired data with racing teams.
In Figure 2 the position of the two systems with reference to the motorcycle and the rider, is shown. The motorcycle unit was placed in the undertail, damped inside a vibration absorbent material; the rider unit was placed inside the aerodynamic appendix of the leather suit, not to impair the rider movements.

Figure 2. Positioning of the recording systems.

Different bikes and motorcycles were instrumented collecting data from eight riders among sixteen different circuits for both 125 and 250 displacements. These racing classes were chosen because being lower the motorcycle-rider weight ratio, and being the overall dynamic subject to faster directional changes, they could be useful for exploring the dynamic response of motorcycle and rider under limit riding conditions.

FALL DYNAMICS

While racing, two are the more common types of fall which can be experienced: lowside and highside.
Lowside [2] [3] [4] (referring to a world fixed triad), is a yaw movement, which normally turns the bike in an over-steering rotation. From a theoretical point of view the typical lowside experienced under race conditions is caused by a uncompensated asymmetry in the distribution of the tyres forces. Once a tyre loose friction with the terrain the centrifugal force and the weight force, which are centred in the centre of gravity, create a momentum that leads the motorcycle to an sudden rotation (Figure 3).

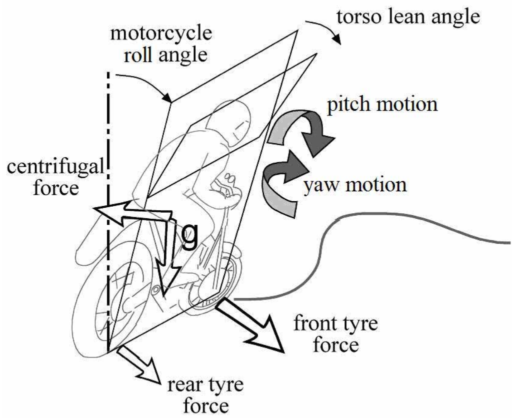

Figure 3. Disequilibrium in the motorcycle adherence forces during a fall.

Due to the high inclination of the bike (over 45°) the yaw moment will be recorded in the motorcycle relative triad, as GZ gyrometer (relative yaw) and GY gyrometer (relative pitch) measurements.

The second kind of typical fall, the highside [2] [3], is an impulsive oscillation around the roll axis, that can lead to a compression of the back suspension with a following upward ejection of the rider. This oscillation is normally caused by sudden lost of adherence with a subsequent traction recovery that creates a disequilibrium in the lateral forces of the tires. Typical condition in which this type of fall can happen is during curve exit, during the acceleration phase and while the motorcycle is slightly tilted. With a bigger roll angle the motorcycle could difficultly regain adherence and the fall would turn into a lowside movement. The less the traction coefficient the smaller the angle at which this fall can happen.

STATISTICAL ANALYSIS OF DATA

Motorcycle is a vehicle intrinsically unstable, especially at low speeds. For this reason the threshold between normal dynamics and fall dynamics can be very thin; and it's difficult to distinguish between them. During races, very high degrees of rotations are experienced.
A statistical analysis can prove helpful in understanding motorcycle movements under extreme driving conditions, and to see the limits of the dynamic behavior. In Figure 4 and Figure 5, statistical trends of respectively motorcycle and rider measurements are reported. Roll angle, longitudinal and lateral accelerations, and gyrometers signals are reported, showing the probability of a certain value being recorded. A value of 1 (dark blue), indicates the most probable recorded value of the signals, where else a value of zero (white), means a never recurring value.
As it is possible to see in Figure 4 and Figure 5, roll angle values normally range from -50 degrees to +50 degrees, but the most typical values are the central and the extreme ones. This means that the more common positions held by a motorcycle during race competitions are the perfect straight line or the maximum roll angle reachable by the rider. This happens for speeding up the turn completion. The values reported for the roll angle, are computed using the GPS so they have to be intended in an absolute reference triad.
Same considerations can be made for the acceleration plots in Figure 4 and Figure 5: the acceleration is maximum during cornering and the more frequent values are the center value and the extreme values. Laterally the maximum acceleration reached is about 17-18 m/s^2, while for what regards the longitudinal acceleration, it's clearly visible an asymmetry between acceleration and deceleration. In particular during deceleration it's possible to reach values up to $12m/s^2$.
Accelerating it's difficult to surpass $7m/s^2$, after the start of the race. It's interesting to note that high values of longitudinal acceleration, are more

frequent exiting from the corners; this happen because when the speed is low and the motorcycle is cornering; the aerodynamic drag force is also low, and so the available trust acceleration is higher. Also in this case values comes from GPS measuring, so they have to be intended in an absolute reference triad.
Both in the roll angle data and in the acceleration data, it is possible to see that positive values are more frequent than negative ones (the sign depends on the reference axis used). This can be easily understood because of the direction of rotation during races; normally tracks in clock wise direction are more common than counter clock wise ones.
The GX gyrometer measurements show a distribution of values which is almost symmetrical and the higher values are reached around the value of 140km/h. The total sum of longitudinal axis rotations along a closed lap, must be zero indeed.
GY gyrometer values are mostly positive because measured in a motorcycle relative triad [2]; they depend on the absolute yaw rate and the roll angle of the bike.
Looking at the GZ gyrometer measurements, it's easy to note, a shape resembling an "up pointing" arrow. As the speed rises, it becomes more difficult to realize high yaw rate turning, because the cornering radius of the trajectories become wider. The higher the forward speed the lesser the cornering yaw speed recorded by the gyrometers. Also in this case is present an asymmetry between positive and negative values; this is again explained with the prevalence of the clock wise circuits.
There are not much differences between motorcycle and rider values because in normal driving conditions the rider can be considered substantially as part of the motorcycle, except for small movements. However it is possible to note some variation in the distribution of the gyrometers measurements. This is because the rider adds to the movement of the motorcycle some independent motion for better controlling the bike and keeping the equilibrium. For example, during braking the rider torso is pointing upward while at full speed is completely leaned horizontally.

FALL MEASUREMENTS EXAMPLES

Coherently with what explained in the theoretical approach, Figure 6 shows what happen during a lowside. The rotational speeds are normalized with respect to a nominal value. Time dependent signals show long yaw and pitch motions, registered by the GZ and the GY sensors, while GX especially for the motorcycle mounted sensors remains shorter. When the fall starts, the motorcycle is already tilted after entering in a curve, so when the sliding motion starts, the main sensors which can record the out of plane movements are the GY and GZ gyrometers.
In the highside in Figure 7, very high values of the GX and GZ gyrometers are recorded on the motorcycle while other gyrometer data reach lower values. This is because the tilt angle of the bike is smaller.
Similarities can be noted between motorcycle and rider recorded data. However as a first instance, there are differences between the two motion, and these became more and more evident as the fall evolves, because the movement of the rider, sliding apart, differs from motorcycle. In every different fall event there is a great deal of variation, since the rider movements can change considerably among the possible cases.
As a general tendency, during a lowside the rider starts the fall rotation movement shortly after the motorcycle; during highside is the same: the motorcycle is the first to experience the sudden rotation around the longitudinal axis. For a better graphs understanding, the peaks recorded during normal driving values are reported using a set of comparative lines.
Looking at the peak normal driving lines, in both type of fall cases it is clearly visible how different are the maximum normal driving values, with respect to fall data registered. In normal driving maximum values of gyrometers never exceed 1/8th of values registered during a sudden fall.

GENERAL TENDENCIES IN THE DIFFERENT TYPE OF FALL

Analyzing different data from various sources, it has been searched for common lines and repeatability between the various falls.
Figure 8 and Figure 9, show a correlation between maximum absolute values and RMS values recorded on the motorcycle and the rider by the three gyrometers axis among 14 different falls. Three of this falls are highside, while the other are all lowside ones.
Graphs show a possible distinction between the two type of fall; lowside tends to have lower absolute maximum and lower RMS values while highside tends to show higher values of both absolute maximum and RMS. In the lowside the rotation is progressive, in the highside instead it comes in the form of sudden burst. This difference is evident from the timings involved in the two events: in the lowside the fluctuations are longer and more progressive, while in the highside they are shorter but more powerful.
Concluding it is possible to isolate two different areas, one which identify lowside and one for highside. This highlight the fact that even if the falls are different, there is repeatability among the fall events of the same type.

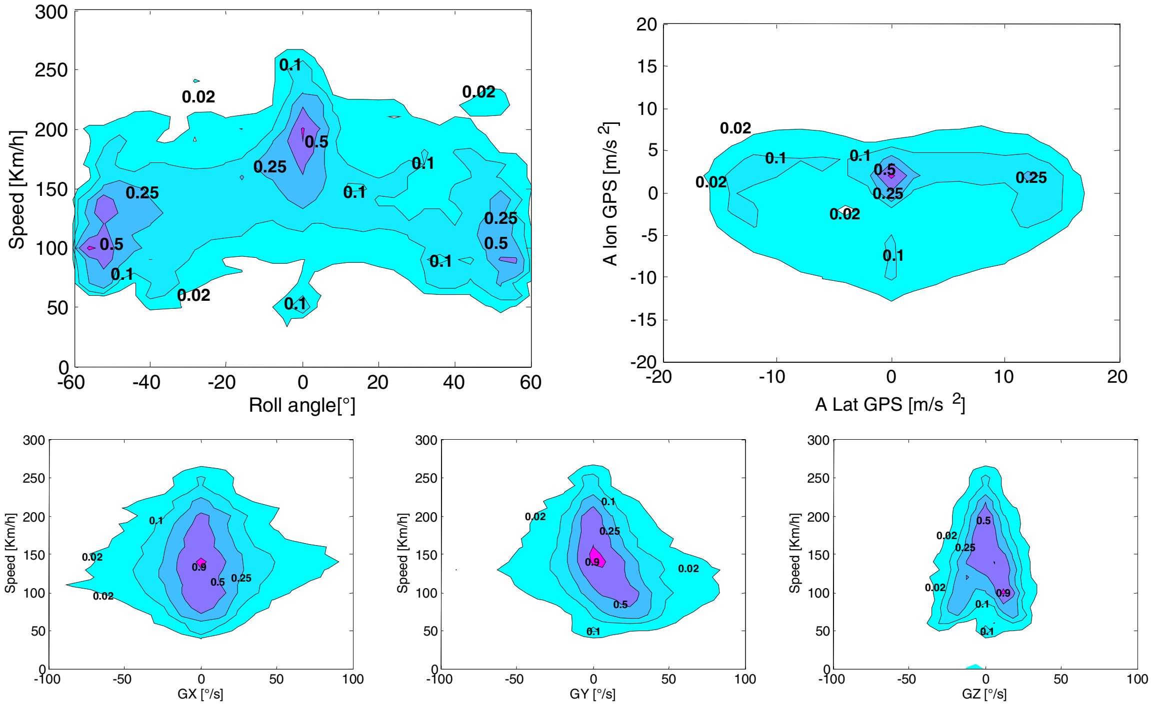

Figure 4. Statistical frequency of the motorcycle signals: roll angle, GPS measured accelerations, GX, GY, GZ, gyrometers data.

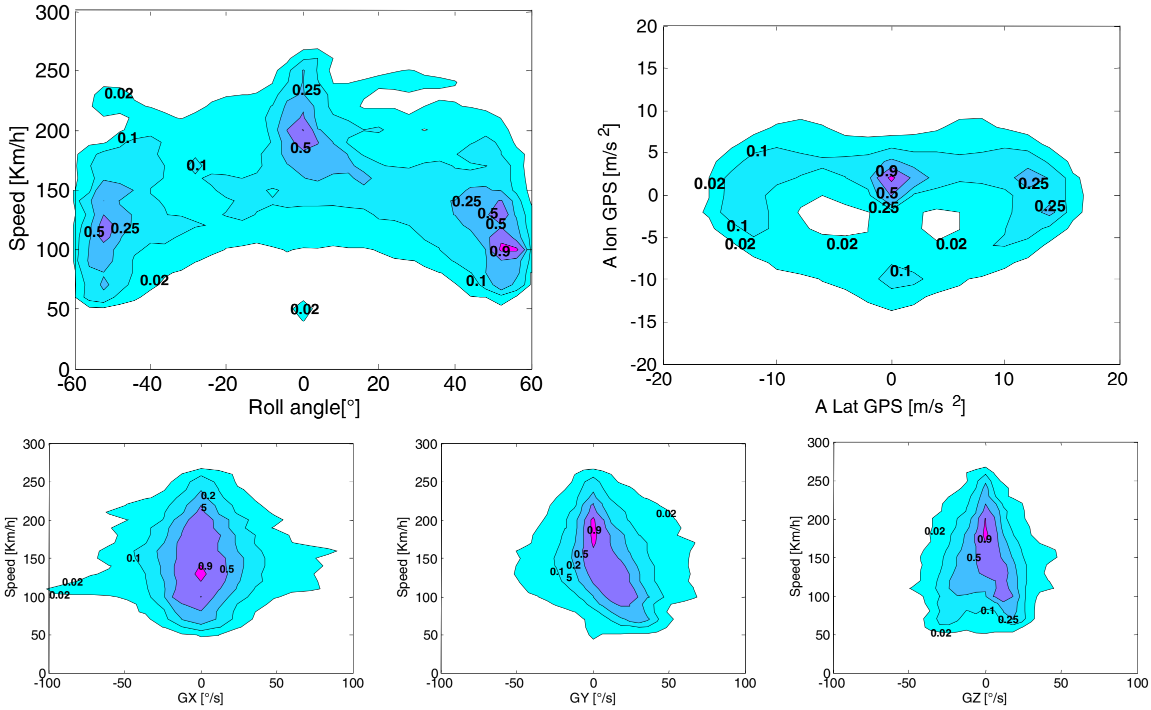

Figure 5. Statistical frequency of the rider signals: roll angle, GPS measured accelerations, GX, GY, GZ, gyrometers data.

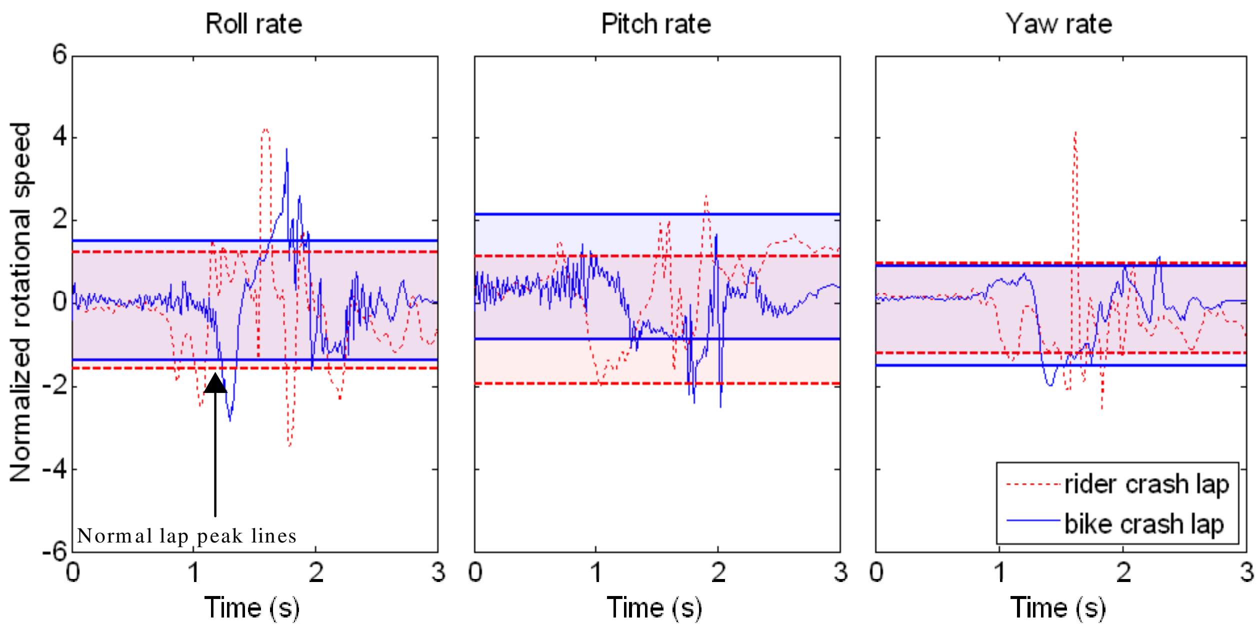

Figure 6. Dynamic measurements of motorcycle and rider data acquired during a lowside fall.

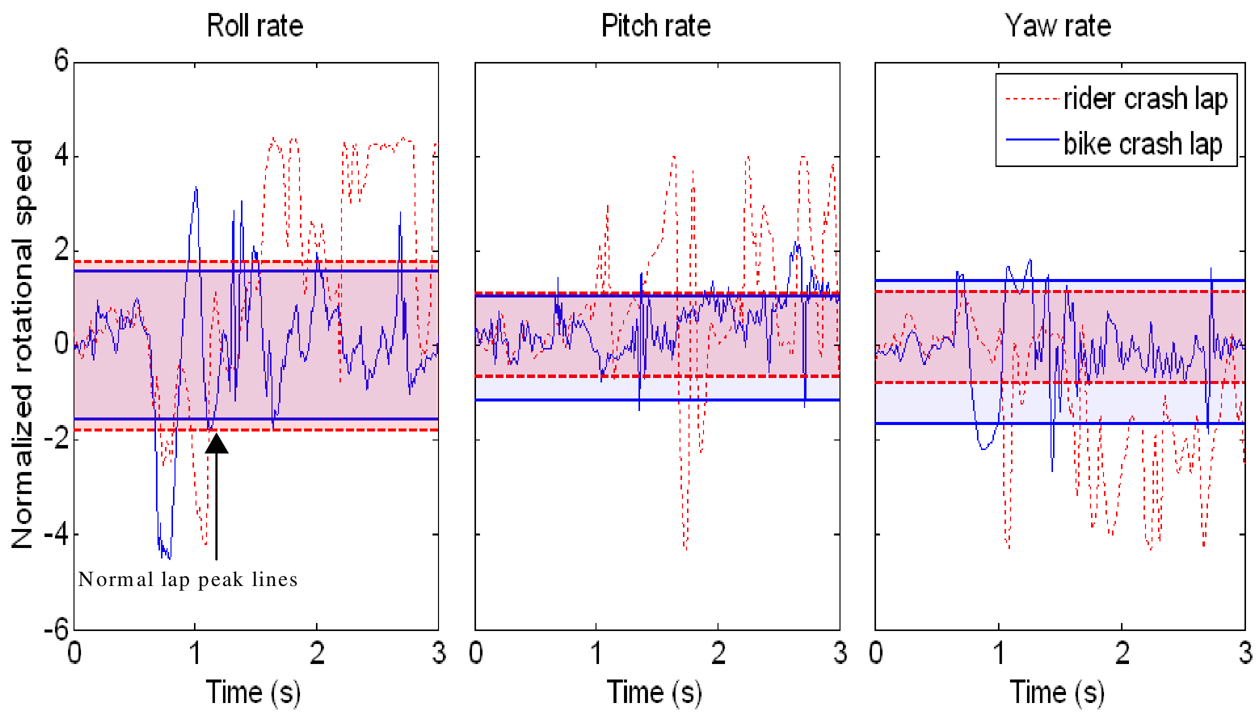

Figure 7. Dynamic measurements of motorcycle and rider data acquired during a highside fall.

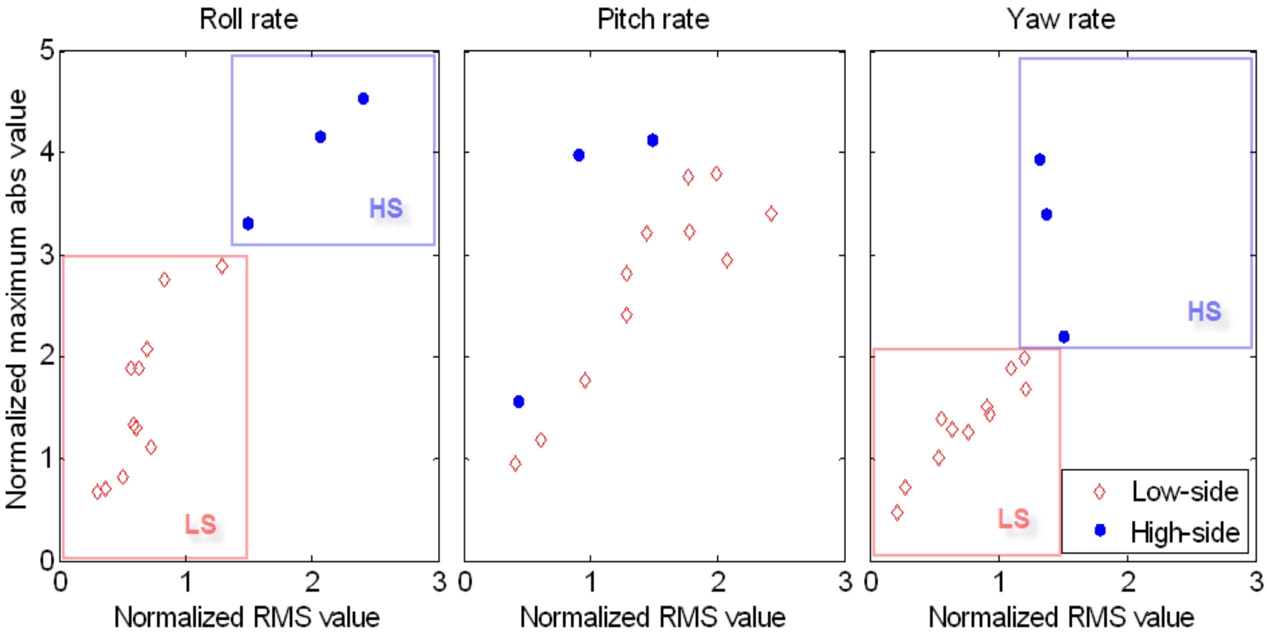

Figure 8. Distribution of the absolute maximum gyrometers values of motorcycle with respect to RMS values.

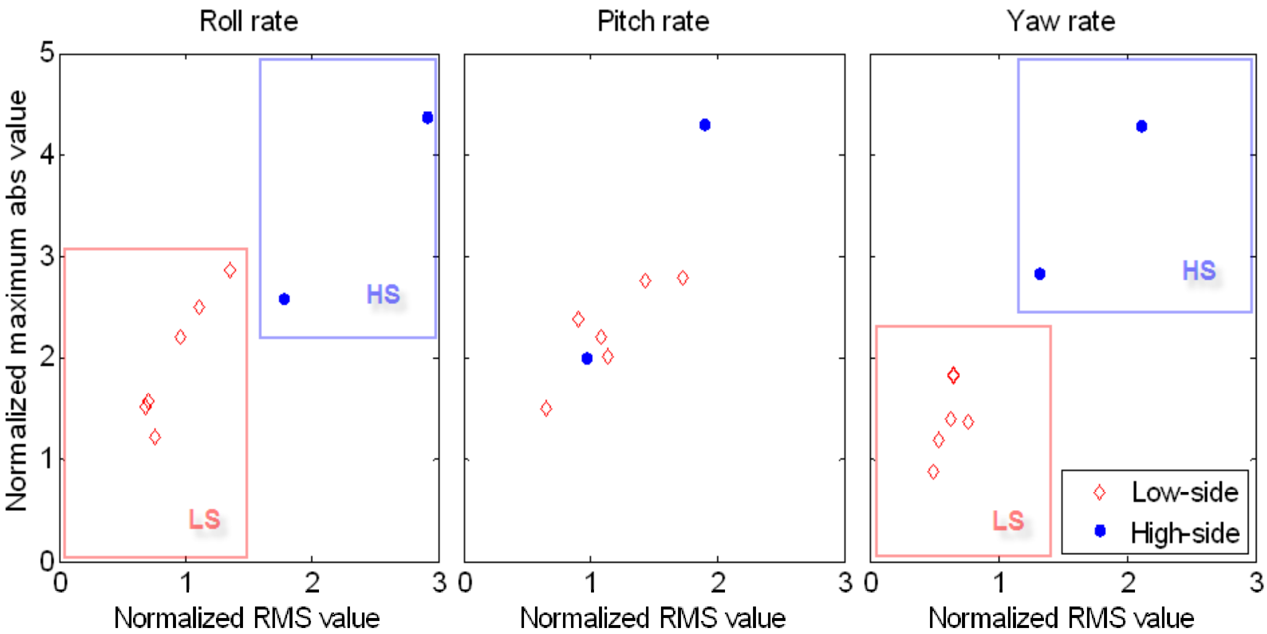

Figure 9. Distribution of the absolute maximum gyrometers values of rider with respect to RMS values.

CONCLUSIONS

Last year, a data collection campaign was carried out, and interesting dynamical data on both motorcycle and rider data were recorded during race competitions.
Example of real falls showing some similarities and differences between the rider and the motorcycle data during normal lap and crash events are presented. General tendencies and common lines in the different fall configurations are analyzed and reported.
This study aim to improve our knowledge of the dynamic behavior of motorcycle-rider system during critical conditions and furthermore to identify some parameters that could be used to improve current and future active and passive safety systems.

ACKNOWLEDGEMENTS

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