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**In-depth study of bend taking practices, towards evaluation and
(re)training tools: the VIROLO++ research project**

**VIROLO++: Tiefenstudie über Kurventechniken, Evaluation und
(Um-) Schulungsmaßnahmen**

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Abstract

The risks associated with Powered Two-Wheelers (PTW) use are a major public health issue in France and in Europe. The main part of the fatalities and injuries relates to interactions with other road users (truck, van and car mainly), but a significant part relates to “single vehicle” losses of control in bends. Several factors can explain such accidents, among them the difficulty to change the trajectory of a PTW while engaged in a bend. New technology (Bosch ESC in particular), that now equips some top of the range PTWs can help, up to some extent, riders to correct a trajectory. But it seems crucial to better train riders to adopt a safe trajectory for bends taking. This is why we started a new research project (called VIROLO++) aiming at producing scientific knowledge on (1) the bend taking practices of riders (novices and experienced ones), (2) the design of an objective measurement tool of the achieved trajectories, (3) the design of a training / retraining tool for safe bends taking trajectories, (4) the design of a model of the interactions during bend taking between the riders and the PTW.

The aims of this paper are (1) to present the VIROLO++ project prospect, (2) to detail the instrumentation that used for the “on closed roads” experiments that will be conducted from May to July this year (2016) – focusing on trajectories, (3) to present the acquired data and the prospects for training tools, (4) to present and discuss the on-going instrumentation aiming at measuring the interactions (pressures) exchanged between the riders and the PTW during bend taking manoeuvres.

**In-depth study of bend taking practices, towards evaluation and
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Context and objectives

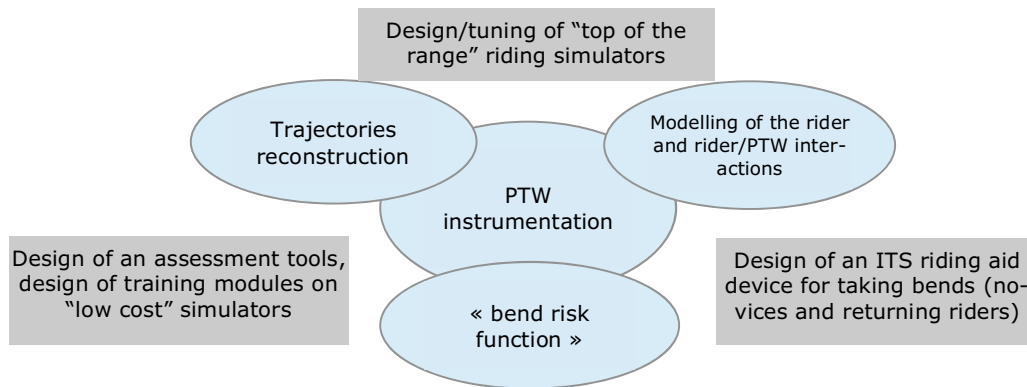
Research on riders of Powered Two Wheeled (PTW) vehicles has only begun fairly recently. Thus, in comparison with the existing literature about car driver behaviour, research into PTW rider behaviour is limited. There remains a lack of knowledge of real riding practices.

From a technical standpoint, the explanations given by the riders of PTWs on how they control the various stages of the bend-taking manoeuvre are diverse. Some riders state that they use a “counter-steering” technique, which consists of pushing the handlebars in the direction of the desired turn. Others explain that they use only their body weight to tilt the motorbike. In addition to the technical aspects, bend negotiation in an open road context is quite different from that practised on a competition circuit. An open road context is characterized by frequent lack of visibility, unpredictable road geometry and surface conditions, and the possible presence of other road users. Thus, any bend-taking manoeuvres rely not only on motor skills but also on cognitive processing of the driving context.

The loss of control in bends (including roundabouts and road junctions) is common largely because of the complexity of PTW dynamics and the intrinsic instability of such vehicles. The MAIDS 2004 study showed that about 30% of all PTW accidents occur in bends or at road junctions. One can estimate, therefore, that loss of control in bends accounts for more than 50% of single-vehicle accidents. In 2012, in France, more than a third of all PTW fatalities occurred in bends (248 killed)².

Counter-measures are needed to improve road safety and mitigate the risk of accidents in bends. In order to do so, it is necessary to observe the interaction between riders and their motorbikes in bends, and compare riders’ statements of how they act with what they actually do. A better understanding of rider behaviour would also make it possible to set up new training and retraining measures. Ultimately, it would help in identifying areas for the design and/or assessment of driving assistance devices dedicated to PTWs. Indeed, the design of active safety systems strongly depends on an accurate knowledge of rider behaviour, because the acceptability of such systems relies on the guarantee that they do not affect the equilibrium of the rider or PTW system. Knowledge of the interaction between riders and their PTWs is also crucial for the tuning of riding simulators, which can then be used by a broader set of the rider population.

The VIROLO++ project, that started in February 2016, is structured around the use of a more- or less-instrumented PTWs; the level of instrumentation depends on the requirements of various proposed studies. The following figure shows the organization of the scientific tasks and the targeted applications.



Understanding and modelling the interactions between riders and PTWs raise several questions. The intra- and inter-individual variability of rider behaviour, as well as the broad range of vehicles classified as “PTW” make the problem even more complex. From a technical standpoint, the acquisition of data takes place in an extremely noisy environment. In addition, it is necessary to take into account the intrinsic constraints of the vehicle in terms of compactness, weight and electrical consumption. In this project we plan to use pressure distribution measurement systems. Pressure will be measured at the rider/PTW contact points: handlebars, saddle, tank and foot pegs. These measures will complement the more usual assessment of vehicle dynamics. One PTW (Honda CBF 1000) will be equipped starting in September 2016, with the objective to conduct experiments in November 2016.

To identify behavioural indicators that allow the reporting of individual differences, we will look at the statistical relations that exist between behavioural representations of riding practices (riders’ statements of how they act) and their objective characterization (what they actually do).

From the acquired data we plan:

1. to improve existing riding simulators (the research riding simulator at Ifsttar) by improving pre-existing sensors in order to allow them to react as quickly as possible to PTW rider's actions (taking into account behavioural variability) and to design a) a commercial low cost riding simulator dedicated to safe bend taking training, and b) a commercial training tool allowing to assess, on road, the practised bend taking trajectories,
2. to design a cybernetic model of steering control which is as close as possible to that achieved by PTW riders. This model will be based on current knowledge in cognitive ergonomics, behavioural neuroscience and human biomechanics. The goal to be achieved - and, indeed, the main scientific challenge to be overcome - is to propose a biologically plausible model that is accurate enough to make predictions about rider behaviour. It must also be economic enough to be implemented in a low cost on-board computer. To succeed, it will be necessary to represent, at an adequate complexity level, the sensorimotor processes used by the central nervous system to control the vehi-

cle: visual anticipation, vestibular perception of the gravitoinertial forces, management of the handlebars, and postural adaptations required to control vehicle tilt. Control strategies may vary between riders; for example, some may counter-steer whilst others do not. These different strategies should be identified using discriminative behavioural markers. Thus, we will study the extent to which a unique model can account for differences through the manipulation of its parameters, or whether alternative models are required.

The modelling (and understanding) of the dynamics of PTW riders has been actively carried out for the past ten years, as shown in an extensive review by Popov et al. (2010). Two approaches coexist. The first approach attempts to set up “black box” type models using well-known optimal control tools, often with a preview function. The second approach, which is closer to ours, attempts to explicitly model the various sensory, cognitive and neuromuscular human functions. To our knowledge, however, no work has succeeded in proposing a synthetic model of the sensorimotor processes implied in PTW control which integrates the various sensory inputs used by the rider (visual, vestibular and haptic cues) and the biomechanics of the postural adjustments that determine how the rider tilts the PTW. Research proposed within VIROLO++ aims to generalize work carried out by IRCCyN (ANR VTT PARTAGE) for the PTW control activity (Mars et al. 2011; Saleh et al. 2013).

The reconstruction of the trajectories achieved when negotiating bends is particularly relevant to objectively assess the observance of instructions (e.g., safety, fuel economy). Such trajectories can be measured using ground-based systems or embedded systems. In terms of this project, the main concern is the accuracy and the genericness of the measurement solutions. Ground-based systems are complex to install and their dissemination in riding training schools seems uncertain. For this reason, we propose to design tools for the reconstruction of trajectories that are based on endogenous sensors.

To succeed, we propose that several localization means be combined in order to increase the accuracy, availability and reliability of the delivered information. From a scientific viewpoint, this raises a problem; it relies on defining the optimal fusing of inertial data (from accelerometers and gyrometers) and GPS data. We will combine the trajectory reconstruction method defined by IEF/Accis (Larnaudie et al., 2006) and the data collected from a GPS. To allow findings to be incorporated into commercial rider training we propose to study the problem in an algorithm-architecture context. Indeed, several architecture designs exist for off-line reconstruction. To our best knowledge, however, this is not the case for real-time on-line reconstruction. The selected architecture will be validated by simulation, and then implemented on a mobile platform. The objective is to achieve an accuracy better than 10 cm for the localization on the road (both longitudinally and laterally).

State of the art PTW instrumentation is poor (McLaughlin, 2011) . Together, IEF/Accis and Ifsttar make up one of the most advanced teams engaged in PTW instrumentation. Their common work has

already been used for the design and tuning of a wireless air-bag jacket system (ANR DAMOTO), and for conducting in-depth naturalistic riding studies (7th FP 2BESAFE and ANR SIM2CO+ noticeably) (Espié et al., 2013).

Two PTWs have already been instrumented and on-road experimentations took place in June 2016. The instrumentation and the very first results are presented later in this paper.

“Bend risk function” design: numerous ITS technologies have been designed to improve the safety, comfort and efficiency of cars, trucks, public transportation systems and infrastructures. However, few technologies have been used on motorbikes compared with cars. There is a lack of literature relating to PTWs (Slimi et al., 2009). Proposed systems mainly consist of car technology being simply transferred to PTWs, without consideration for the specificities of the PTW riding activity. The 6th FP PISa, and SIM projects, and the 7th FP SAFERIDER project, have all dealt with the design and tuning of PTW ITS, often with limited validation and assessment phases. A literature review shows a significant delay in ITS research and development for PTW safety.

Due to the specific dynamics of PTWs, bend-taking is a difficult manoeuvre. A non-adapted speed is particularly difficult to correct because it is practically impossible to brake when negotiating a bend. It is crucial to “read” the bend; however, the ability to do so is based on experience-related know-how. Novices have the greatest difficulty in adapting their speed to a bend’s geometry (a fortiori for a sequence of bends). The ESC system from Bosch, which was recently introduced on “high-end” motorcycles only partly responds to the road safety question. Indeed, measures to correct badly balanced front/rear braking are only able to manage situations in which there is “limited” excessive speed. Moreover, the vehicles often used by novices (mid-size segment vehicles, often second hand) are not likely to be equipped with such safety systems in the near future. Indeed, it is estimated that it will be at least twenty years if we look at the time that was needed to introduce ABS onto the motorcycle market. ABS was first introduced in 1988 by BMW; however, in 2012, only an estimated 13% of the French PTW fleet was equipped as such, the percentage being roughly 30% for PTWs over 750cc.

The design of riding assistance devices aimed at alerting riders that they are approaching a bend too fast was alluded to within the 7th FP SAFERIDER project. However, the project failed to answer questions relating to the acceptability issue and large-scale deployment on a road network with such infrastructure characteristics as a lateral profile. In terms of acceptability, a major concern relates to the perverse use of any driving assistance device, whereby riders “play” with the proposed speed. Within VIROLO++, we intend to focus on novices and returning riders. Two reasons motivate that choice: firstly, the over-representation of novices in PTW accidentology, and the difficulties this population has in “reading” bends and selecting an appropriate speed. Secondly, the risk of perverse use

is limited because novices have not yet developed over-confidence. Moreover, we plan to promote the system's use under the control of trainers.

Instrumentation of PTWs, towards trajectories reconstruction

Three PTWs were expected to be instrumented during the VIROLO++ project: 2 from the Gendarmerie Nationale (GN) training school, and 1 from Ifsttar. In fact, Yamaha France (provider of GN at national level) loan us 2 PTWs for our experiments: one MT07 and on FJR 1300, both are representative of the PTW used by the GN training school and later by GN motorcyclists. The third PTW, from Ifsttar is a Kawasaki ER6n.

As previously stated, the aim of VIROLO++ is to design a low cost (i.e. acceptable for training schools) system able to reconstruct the achieved trajectories with a precision, better or equal, to 10cm. To reach such an ambitious goal, we set two important limitations: 1) the observed trajectory length is lower than 5km, and 2) the starting and ending points are precisely known. We consider that these two constraints are acceptable for riding schools, and within the project the GN selected two road sections they commonly use to assess their trainees.

The question of price will clearly forbid the use of expensive sensors, so we decided to test the use of low cost ones and compare their performances with top of the range ones (we called them "reference" sensors). The methodology we used consist in instrumenting one of the PTW with both low costs and "reference" sensors. For compactness, weight, electrical consumption, modularity and non intrusiveness reasons we redesigned a new version of the instrumentation previously used in the SIM2CO+ project. The system is design using CAN "nodes". Sensors are "canized" (i.e we add a microcontroller that collect the data and send CAN messages, either for the GPSs) and a data logger has been designed to store the messages on a USB memory (a stick or a SSD).

The test instrumentation consists in (Kawasaki ER6n) :

1. Steering wheel angle: magnetic sensor, 14 bits resolution, that give us a 0.17° precision. The acquisition frequency has been set at 100Hz,
2. Road wheel position: optical encoders in quadrature, using the ABS disk, 200 ticks per wheel revolution for a 50 holes ABS disk. The acquisition frequency has been set at 100Hz,
3. Inertial measurement units 1 & 2: 9DOF Xsens and 10DOF InvenSense (MPU9250 IMUs, commonly used for drones). The acquisition frequency has been set at 100Hz, we retrieve accelerations, rotation speed and Euler angles (using an additional algorithm for the 10DOF)

4. Lasers: two lasers measuring the distance to the pavement, one at the right and one at the left of the PTW frame. The acquisition frequency has been set at 100Hz,
5. Brake and turn signal contacts: we pick up the signals on the PTW wires. We don't modify the braking system for certification issues. The acquisition frequency has been set at 5Hz,
6. GPS: a RTK one at 25Hz and a "classical" one at 5Hz,
7. High speed video camera: one camera (global shutter, 150 fps) looking at the front of the PTW,
8. Data logger



Picture 1. some sensors on the Kawasaki: wheel, the two IMUs, a laser

For the MT07, we used a subset of this instrumentation, without the lasers and the video camera. Note that the compactness of the instrumentation/ data-logger (no need for a top-case).



Picture 2. the MT07 with some sensors: IMUs, steering wheel, RTK-GPS

Experiments, and first lessons

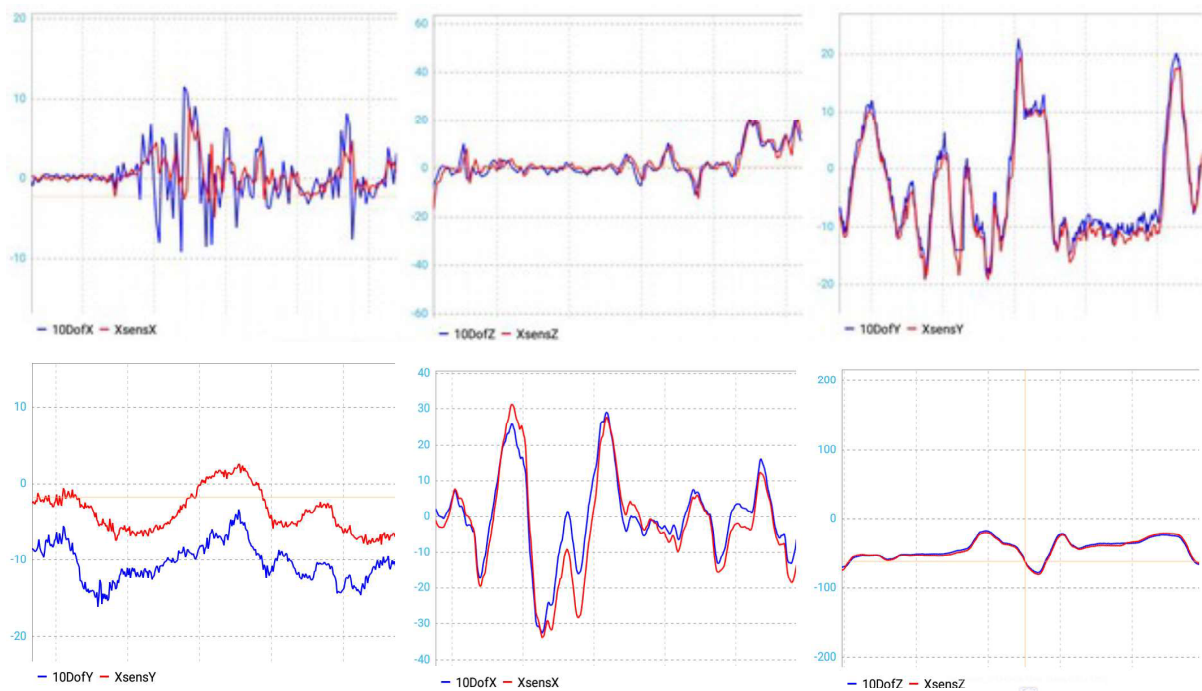
Within the project, the plan is to record the trajectories achieved by at least 20 riders. As the prospect is to compare the trajectories achieved by GN trainees to those achieved (or defined) by GN trainers, we choose to record the trajectories achieved by trainers, trainees at the beginning of the training course and trainees at the end of the training course, we will later call novices. Note that a specificity of the GN recruitment is that the recruited people have or not a "civil" riding license, thus we expected to measure the trajectories of very "random" riders and in particular before they follow the GN dogma for safe bend taking.

We conducted several experiments to tune the instrumentation. Then, we conducted two experiments with the GN instructors and trainees. One other experiment is planned in September 2016.



Picture 3. the selected trip, roughly 5km length

The data are currently being analyzed.



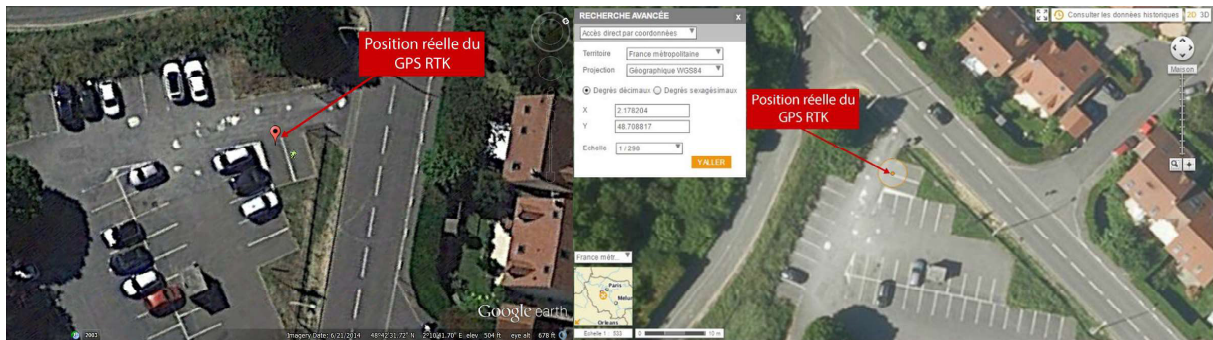
Picture 4. Snapshots of the acquired data (IMUs): a_x , r_y , m_z ; Euler angles pitch, roll and yaw. Note the offset for the pitch.

The two IMUs provide coherent data. However, the data provided by the Xsens is more filtered (including a delay), and we noticed a progressive shift in the magnetometers. The InvenSense provides

more noisy data, at lower speed, and the test we conducted to use the internal Digital Motion Processor was not successful, so we used an additional software algorithm to obtain the Euler angles.

The very first lessons of our tests are:

1. The difficulties to use GPS on real roads, to visualize data on maps, and to use jointly GPS data with odometry data: one of our objectives is to succeed to reconstruct “precise” trajectories using low cost sensors. The trajectories are achieved on open roads, where sequences of curves exist.
 - GPS precision, and coverage: standard GPS have a precision lower than one meter, while RTK GPS are supposed to give centimetric precision. However, these performances are achieved in “perfect” conditions (i.e. no corridor, good weather, and for the RTK-GPS good communication between the base and the rover). In real life (countryside roads for instance), these conditions are rarely existing: the terrain is not flat, the sequences of bends are often in road sections bordered with trees. Thus, the GPS localization is not optimal, the base – rover communication often don’t work due to occlusion, and the best performances are not reached.
 - GPS localization vs odometers: the conversion from GPS coordinates to “ground” meters is still an open question (see Mohinder et al. 2014 appendix C, and μ -Blox 1999 application note on Datum Transformations of GPS Positions for an in-depth discussion), thus it is complex to mix for instance distances provided with GPS and distances measured using odometers, at least for a “centimetric” precision. We are currently working on this issue.
 - GPS localization and maps: it is very convenient to visualize the acquired / reconstructed trajectories using images issued from satellites or planes. Unfortunately, it appears that the maps are not precisely “localized”. We conducted a small experience using the RTK-GPS (optimal conditions, centimetric precision) that consisted in positioning the rover at specific points easily recognizable on satellite based maps (i.e. specific horizontal road marking points). On Google Earth, we observed localization errors up to 60cm, and unfortunately the error is not constant over the maps (different points on the ground give different errors). Fortunately, using the satellite based maps from the French Geographic Institute (IGN), we did not observe such localization errors.



Picture 5. Localization on maps examples (red arrows show the precise localization of the rover), left Google earth, right IGN

To summarize, the use of RTK-GPS, as well as standard ones, is limited as the optimal precision is obtained only in optimal situations that don't often exist in real life. The use of satellite based maps needs to be validated on a case by case basis, and the mix of data obtained by GPS and by odometers are fairly complex as far as the requested precision is "high" (for us centimetric).

2. The use of lasers to measure the PTW leaning angle: the two lasers beams provide us with a distance measurement, one laser being on the right of the PTW, the other one on the left, both pointing the pavement. When the PTW is leaned to the right, the right distance is shortened, while the left one is enlarged. The measurement system is theoretically "perfect", but in reality several problems occur: the road pavement is not flat (to allow water to be evacuated), the pavement surface is sometimes reflective (peculiarly when wet), and the laser beam is sometimes outside the pavement (when the trajectory is too close to the pavement border and the leaning angle is important). So, in fact, the laser beams are usable mainly on "large" tracks, to validate the measurement provided by the IMUs (note that IMUs do not measure leaning, but provide a value by integration of "direct" measurements).

Conclusions and prospects

One can estimate that loss of control in bends accounts represent more than 50% of single-vehicle accidents. In 2012, in France, more than a third of all PTW fatalities occurred in bends (248 killed)¹. Counter-measures are needed to improve road safety and mitigate the risk of accidents in bends. A better understanding of rider behaviour in bends sequences would make it possible to set up new training and retraining measures.

The VIROLO++ project aims at designing a set of counter measures for riders' safety. One of these counter measure consists in the design of a curriculum for the training of safe bends taking practice. A

¹ Source ONISR (The French Road Safety Observatory).

pre requisite is an objective and precise measurement of the trajectories achieved by trainees in a sequence of curves. This paper aims at presenting the overall project, and the preliminary work achieved towards trajectories measurement and/or reconstruction.

Two PTWs have been instrumented with an ad-hoc instrumentation and data collection on road have been achieved. The data analyse is under going. The future work will consist in: the selection of a subset of low cost sensors allowing to measure/reconstruct the trajectories with a precision better or equal to 10 centimetres (our ambition), and the design of tools allowing to objectively compare the safe trajectories defined by trainers, and the trajectories achieved by trainees.

Further work will focus on the set up of a “heavy” instrumentation allowing the measurement of the efforts exerted by the rider to take bends and on the achievement of an experiment on track. This experiment is planned at the end of 2016.

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