Ph.D. Thesis Subject VS-FROG

Title: Modelling, designing and prototyping a Very Safe Four-wheeled terrestrial Robot for rolling at high speed On uneven Grounds (VS-FROG).

Context: Nowadays, most of wheeled robots are designed for moving at low speeds on flat grounds, thus considerably limiting their possible applications However, it is sometimes necessary to have a terrestrial autonomous wheeled vehicle able to move quickly on uneven terrains (e.g. inspection and fast intervention on agricultural fields, forests, airports, disaster areas). Thus, the robot must be able to adapt its dynamic properties for preserving its integrity (e.g. shock absorption, obstacle crossing), or even preparing its landing in case of take-off. The aim of this work is focused on the development of specific mechatronics devices (e.g. active suspensions, inertial tilt adjustment), associated with perception and control approaches (inertial and visual sensors), able to change the robot parameters in order to avoid risks occurring during fast off-road motions.

Within the scope of this Ph.D. thesis, several active devices will be considered. Experimental VS-FROG robots will be equipped with four specific additional devices in order to adjust their attitude on the floor and to ensure their safe landing in case of an unintended ballistic phase:

- Innovating suspension with four mobilities (Susp4D [5], follow-up of ANR FAST project, Fig.1): it allows longitudinal damping of shocks on high obstacles with respect to wheel radius, thus limiting risks of roll-over and tip-over at high speed;
- Active suspension composed of vertical and horizontal shock absorbers with adjustable damping coefficient using magneto-rheological technology, for instance;
- Dynamic attitude adjustment during a ballistic phase: this adjustment will be performed on pitch axis using Robcat's technology (Fig. 2, LabEx thesis of Marc DAVIS [3, 4, 8, 9]), but also on roll and yaw axes (these adjustments should be modelled and implemented);
- Highly reactive embedded control capable to perform the above adjustments within a few hundredth of seconds, thanks to control schemes and embedded sensors to be defined [1, 2, 6].

These devices will allow VS-FROG robot to roll on all type of uneven grounds and to adjust its airborne attitude (dynamic stabilisation) according to the features of the ballistic phase and of the landing area. The achievement of this subject requires (i) to model motions and actions of the VS-FROG robot on the ground, when approaching an obstacle, during a ballistic phase and at landing, (ii) to develop control commands for performing these actions, and (iii) to design and build the corresponding mechatronic devices, namely an active damper (e.g. a magneto-rheological one) that will be duplicated at two scales: for VS-FROG demonstrator (length: 0.5 m) and for Adap2E demonstrator (length: 2 m, Fig. 3).

Subject: The thesis will be mainly focused on modelling, design and control of mobile robots. It will aim at creating and developing specific mechatronic devices (e.g. active suspensions, attitude adjustment devices), as well as their control commands, in order to adapt the mobile robot behaviour while it moves very quickly in its environment, and to preserve its stability and its security. This Ph.D. thesis will benefit from the expertise acquired in previous collaborative projects (ANR FAST, ActiSurTT, Adap2E) and actions (CoroDyn, RobDyn) within the LabEx, and will be split into three steps:

1. Synthesis of adaptive mechanisms acting on the robot dynamic properties (e.g. suspensions properties, height of the centre of mass, tilt adjustment);
2. Definition of fast and reliable sensors for detecting obstacles before dynamically crossing them and for evaluating the characteristics of the landing area at the end of a ballistic phase;
3. Design of high speed command of corrective devices in order to keep the vehicle integrity while taking its dynamics into account.

From adaptive and predictive principles, this work will allow, on one hand, to estimate the risks induced by highly dynamic displacements, and, on the other hand, to command the devices able to change in real-time the robot dynamic properties in order to preserve its stability and its security.

The Ph.D. student will be supervised by three French searchers (see below) and an invited Professor whose mission will be mainly focused on design, manufacturing and experimenting an active damper (e.g. a magneto-rheological one) that will be duplicated at two scales: for VS-FROG demonstrator (length: 0.5 m) and for Adap2E demonstrator (length: 2 m). All the team will participate in high speed experimentations that

1 Adaptive and autonomous production platform for environment: https://adap2e.irstea.fr/
will use LabEx equipment (e.g. high-speed video cameras). At the end of the thesis, a technology transfer to a manufacturer may be considered.

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References
Fig. 1: The patented Susp4D suspension with four mobilities (wheel driving rotation, wheel steering rotation, wheel vertical damping translation, wheel horizontal translation). a) Kinematic description. b) Implementation on the front axle of a vehicle.

Fig. 2: RobCat prototype for pitch angle correction in ballistic phase. a) Test bench. b) Example of a non corrected jump on a standard vehicle leading to a crash at landing.

Fig. 3: Several behaviours in Adap2E project: a) Edge following, b) High speed path tracking, c) Path following on irregular grounds.