Adaptive and predictive control for off-road mobile robots path tracking.

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Abstract:

If the development of algorithms dedicated for path tracking control of mobile robots is a well-known problem under the rolling without sliding condition (for vehicles moving on road for example), transfer of such control techniques are not always relevant for the case of mobile robots moving off road. Indeed, the application of control techniques developed under this assumption for off road vehicles demonstrates some unexpected behaviour, which depreciated considerably precision of a trajectory tracking (especially when vehicle executes a curve on a low adherent surface or when moving on a slope). Moreover, actuators used in natural environment are often more powerful and consequently less reactive, what introduces delays in vehicle dynamics. Such delays are emphasized by inertial effects, as the stability of off road vehicles requires the use of more important mass (and then inertia). An algorithm, taking into account for such phenomena and preserves the precision of path tracking for mobile robots, is presented. Capabilities of this approach are investigated through full-scale experiments, on farm tractor. Assistance of agricultural works indeed constitutes the application field of theoretical developments presented.

If localization problem is often an important topic for those robots, it is not considered here. Indeed, the approach here proposed is focused on single exteroceptive sensor (a Real Time Kinematic GPS), which supplies an accuracy of 2cm on coordinates signal at a sampling frequency of 10Hz. In addition, an angular sensor, based on steering wheel is present to ensure servoing of low-level actuator. Steering angle is here the unique control variable to be calculated, and velocity of robots is tuned manually and viewed, in control law, as a measured parameter, which can be variable.

Considering this measurement system and the numerous parameters required by a wheel-soil interaction model in a dynamical approach, the use of complex dynamical models (such as Pacejka or LuGree) is rejected. Instead, an extended kinematical model, adapted to describe sliding effects is designed. It takes account for vehicle behaviour (including sliding, which inevitably occurs on low adherent terrain) by the integration of two sliding parameters homogeneous to sideslip angles. However, it is necessary to estimate these parameters in order to feed the model and access to an accurate description of vehicle dynamics, with respect to the unique sensor approach. As considered parameters cannot be measured directly, an observer-based approach is then proposed, turned into a suitable way, in accordance with the duality between control and observation problems.

As an accurate model is then available, and considering this non-linear model can be turned into a linear one using a chained system form, a control law can so be designed. This law is able, on one part to compensate sliding phenomena in slow varying conditions, with respect to

observer performances, but, on the other part, delays presents on actual vehicle (due to actuator properties and inertial effects) are neglected. As a result, accuracy of path tracking is preserved when sliding phenomenon can be considered as slow varying, but overshoots are present during transient phases. It is mainly the case during curve transition, appearing at begin or end of a curve.

Considering, that in path tracking case the entire trajectory to be followed is known and assuming on that it is possible to extract a model of the actuator response to a step of steering consign, a Model Predictive Control is introduced in the algorithm. Predictive action is here applied only on a part of control law, dedicated to the curvature servoing. An horizon of prediction is defined, allowing extraction of a future consign relevant with respect to reference path future configuration. Using the low level model, the actual steering angle can be predicted and error in the future between desired response and actual one can be computed. Then, the prediction algorithm consists in finding the set of control on the horizon of prediction, which minimizes this error. The first value of this set is then applied on the part of control dedicated to curvature servoing. As a result, overshoots are considerably limited. Moreover, even if only a low level model is considered, this predictive action is able to compensate implicitly delays induced by inertial effects. The accuracy is then also preserved during transient phases of curvature.

Finally, the global algorithm allows to achieve a high accurate tracking for off road mobile robots, whatever the path to be followed is, whatever the conditions of adherence are, and whatever configuration of terrain is (flat or sloppy ground). Accuracy reached by this control techniques (including adaptive and predictive actions), is close to sensor precision (considering the noise introduced by the roll effects of vehicle) during actual path following. Full scale experiments show that the vehicle is able to stay inside an acceptation interval of ±15cm. With respect to the application field, such accuracy meets the farmer expectation for agricultural tasks.