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Estimating the maneuver quality of an automatic motion inverter for end-of-line tuning in agricultural tractors ⋆

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Abstract : End-of line tuning is a crucial step for any mass-produced system endowed with automatic controllers. As a matter of fact, due to components tolerances and spreads in the production line, the controller tuning performed on a prototype system in never optimal on the final product. In many industrial applications, though, the end-of-line tuning is performed by human testers, and this does not always guarantee an objective assessment of the controlled system quality. This paper proposes a way to estimate the maneuver quality from measured data for an automatic motion-inverter in agricultural tractors. The final goal is to automatically classify the performed maneuver and label it with a quality attribute matching that assigned by the driver. This is the initial step necessary to implement an automatic tuning system which can change the controller parameters until a predefined quality on the motion inversion is achieved.

Keywords: Power-shuttle transmission; agricultural tractors; end-of-line tuning; automotive systems.

1. INTRODUCTION AND PROBLEM SETTING

In industrial applications, when the final product is endowed with automatic control systems, a crucial step in the production line is the so-called *end-of-line tuning*. This phase is tailored to optimize the controller parameters tuning to each final system, which is always somehow different from the prototype on which the controller was designed. This is even more important when the final product is a complex system, on which multidomain sub-subsystems (*e.g.,* electrical, hydraulic, mechanical, electronic and so on) have to work together, as it is the case in the automotive industry, Isermann [2003], Barron and Powers [1996]. Very often, though, the end-of-line tuning is performed by human testers, and this does not always guarantee an objective assessment of the controlled system quality.

This paper proposes a way to estimate the maneuver quality from measured data for an automatic motion-inverter in agricultural tractors. The final goal is to automatically classify the performed maneuver and label it with a quality attribute matching that assigned by the driver. This is to be seen as the initial step necessary to implement an automatic tuning system which can change the controller parameters until a predefined quality on the motion inversion is achieved.

The objective of the motion-inverter is to perform a fully-automated motion inversion, which takes the tractor from a forward speed of - say - $10\,km/h$ to a reverse speed (not a-priori fixed), which corresponds to a fully engaged clutch. The device (reverser) used for the automatic motion inversion is an electro-hydraulic system, constituted by two clutches, driven by a Proportional Electro-hydraulic Valve (EVP) and by an on-off Directional Electro-hydraulic Valve (EVD). The Electronic Control Unit (ECU) of the transmission drives the currents of these valves (which constitute the main control variables); the measured variables are the input/output rotational speeds of the reverser, the engine speed and the wheel speed.

The design of the motion-inverter control system (see *e.g.,* Savaresi et al. [2006]) is a non-trivial task, as it is difficult to find a good compromise between speed (the complete motion-inversion task should be performed in the shortest possible time) and comfort (bumps and oscillations on the longitudinal speed must be minimized). Thus, the two main features of the inversion maneuver quality which have to be taken into account are the maneuver *duration* and the maneuver *comfort*.

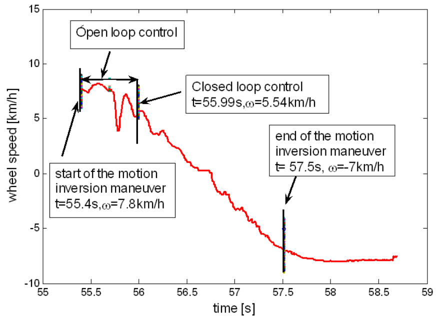

Figure 1. Behavior of the wheel speed during a Forward→Reverse motion-inversion, which was labeled as *bad*.

To better understand the aim of the quality evaluation problem, consider the signal displayed in Figure 1. This signal represents the wheel speed (in [km/h]) of the tractor. The inversion starts at a forward speed of $7.8\,km/h$ and ends (after about 3s) at a reverse speed of $-7\,km/h$. In principle, the ideal behavior of the speed is constituted by a smooth ramp. Instead, notice that it strongly differs from this ideal behavior: the first part of the inversion is affected by filling-delays in the oil-chambers of

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the clutches, and this results in oscillations in the output speed. The inversion displayed in Figure 1 contains all these negative aspects; the result is an uncomfortable inversion. In fact, the human tester which performed the maneuver shown in Figure 1 labeled it as *bad*.

This paper aims at defining a cost function which takes into account both duration and comfort and - based on the available measured signals - outputs a label which classifies the performed maneuver together with the cost function value, and whose output can possibly give some indications about which controller parameter is responsible for the lack of quality. For the purpose of this work, several maneuvers have been performed by a driver who manually de-tuned the controller and who labeled each inversion as either *good*, or *medium* or *bad*. We will show that the proposed automatic assessment process correctly matches the driver's perception.

The presented results are based on a joint work between Politecnico di Milano and the R&D Department of the SAME Deutz-Fahr Group (SAME, Lamborghini, Deutz-Fahr, Hürlimann, Adim Diesel and Deutz AG). This work has been developed on a Power-Shuttle transmission designed for low-power (80-100HP) agricultural tractors (see Figure 2).

Figure 2. The Explorer3 tractor employed in this work.

2. SYSTEM DESCRIPTION

The overall scheme of the Power-shuttle transmission used in this work is displayed in Figure 3. Moving from left (engine) to right (wheels), notice that the transmission is mainly constituted by the reverser (oval box), the three main clutches (Low, Medium, High), and the synchro. The reverser and the three main clutches are controlled by the ECU, which drives the Electro-Hydraulic valves.

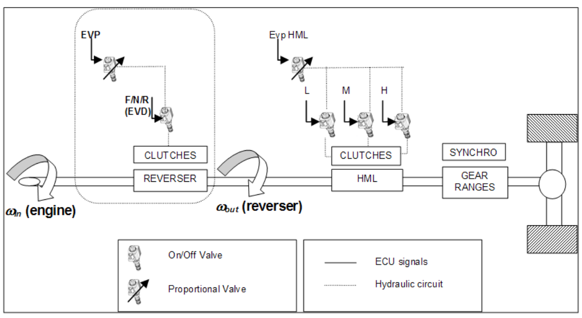


Figure 3. Scheme of the power-shuttle transmission.

Note that the reverser is cascaded with the rest of the transmission. Our work will focus on this part of the transmission only. As already said, the reverser is actuated by two Electro-Hydraulic valves: a proportional valve (EVP) and an on-off directional valve (EVD), which can assume three positions: F (Forward), N (Neutral) and R (Reverse). The measured variables are the input rotational speed of the shaft ω_{in} (which is equal to the engine speed), the output rotational speed of the shaft ω_{out} and the wheel speed ω_w.

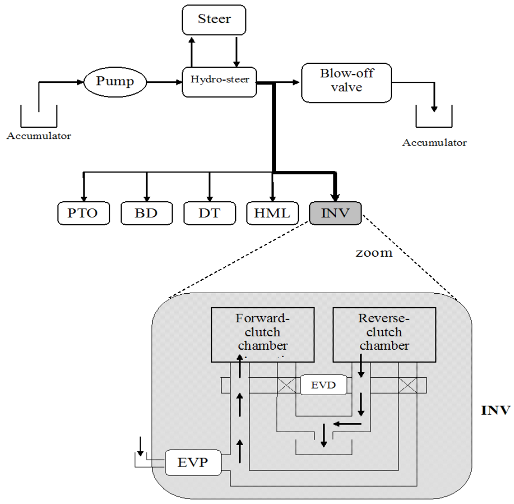


Figure 4. Schematic representation of the hydraulic circuit.

A schematic diagram of hydraulic circuit which drives the reverser is displayed in Figure 4 (see *e.g.*, Cheng and De Moor [1994], Scarlett [2001], Setlur et al. [2001], Tanelli et al. [2007], Bosch [2000]). Note that the hydraulic circuit is mainly constituted by an accumulator, a pump, and many hydraulic *users*: the hydro-steer, the Power-Take-Off (PTO), the differential-locking system (BD), the 4-wheels traction (DT), the HML clutches, and the inversion system (INV). The inversion system (see detail in the zoomed part of Figure 4) is constituted by two clutches (Forward and Reverse); each clutch is activated if the oil in the corresponding chamber is pressurized. The aim of the motion-inversion controller is to synchronize the activation and the de-activation of these two clutches, in order to provide smooth transitions from one clutch to another. This can be done by means of two Electro-Hydraulic valves: the directional valve (EVD), which is a 3-positions (Forward, Neutral, Reverse) 4-ways on-off valve; this valve is used to activate and de-activate the two-clutches; the second valve is a proportional valve (EVP), which modulates the pressure in the clutch chamber.

3. CONTROLLER DESCRIPTION

This Section is devoted to briefly illustrate the control system which takes care of the automatic motion inversion, as it is needed to understand how the design of the quality cost function. The overall controller is split into the open-loop phase, which controls the switch of the EVD valve and the open-loop modulation of the EVP during the fist part (about 0.5s) of the inversion and the closed-loop control of the speed of the output shaft of the reverser, using the controlled EVP.

3.1 Open loop control

When the driver requires a motion inversion (this is done by manually activating a lever), the automatic control system takes full control of the maneuver, until the clutch in the opposite direction is fully engaged. A complete inversion (starting from a maximum speed of $13km/h$) usually takes $3-5s$.

Note that an inner control loop has been designed for the regulation of the EVP current. We do not describe here the inner current loop design, as it is not critical for the maneuver quality (see Savaresi et al. [2006] for details on this phase).

When the automatic inversion procedure starts, the first phase of the inversion algorithm is performed in open-loop (this phase takes about 0.5s). During this open-loop phase the following actions are taken (consider, for example, an inversion from

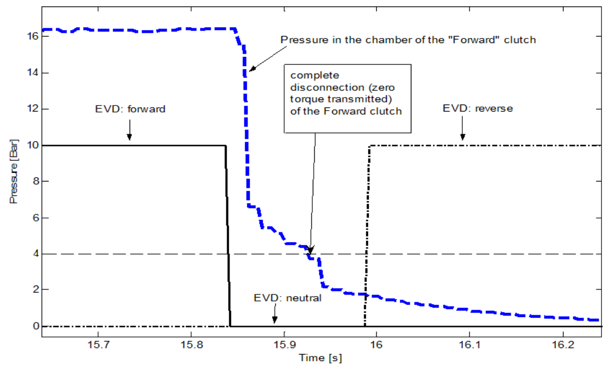


Figure 5. Switching strategy of EVD.

Forward to Reverse).

EVD: When the inversion procedure is triggered by the driver, the EVD - which was originally in the Forward position - is immediately switched to the Neutral position (see Figure 5); as the EVP is closed, the pressure in the chamber of the Forward clutch immediately drops; when this pressure goes below (about) $4 Bar$, the Forward clutch is completely disconnected (no torque is transmitted through this clutch). When the disconnection of the Forward clutch is completed, the EVD switches to the Reverse position, and the chamber of the Reverse clutch starts being filled. In practice (see Figure 5), since the output pressure of the EVP is not measured, the EVD is switched from Neutral to Reverse not immediately after the pressure in the Forward chamber drops below 4 Bar, but after exactly $150 ms$. This time window has been empirically estimated in order to guarantee the complete disconnection of the clutch in every working condition.

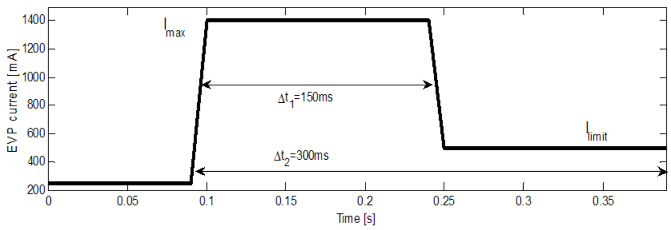


Figure 6. Modulation of the EVP-current during the open-loop phase.

EVP: The open-loop strategy on the EVP is more complex than that on the EVD, since the EVP allows a continuous modulation, Savkin and Evans [2002]. When the inversion starts, the EVP is immediately fully closed, in order to allow the quickest pressure drop in the Forward clutch. When the EVD is switched to the Reverse position, the EVP is reopened, in order to allow the rise of the pressure in the Reverse clutch chamber. The open-loop control design problem is to find the best shape of the EVP current, in the 300-400ms before the closed-loop control on the forward vehicle speed is activated. The open-loop EVP-current shape is displayed in Figure 6: when the EVD is switched into the Reverse condition ($150 ms$ after the inversion is triggered), the EVP current is switched to its maximum value I_{max} and kept at this value for $150 ms$. Notice that - even if the EVP current is high during this time-window - the actual transmitted torque does not move the vehicle. In fact, the clutch chamber must be filled (when the Reverse clutch is activated, its pressure is very low, and it is partially empty). Thus, the best strategy is too keep the EVP current at its maximum value, in order to increase the pressure in the camber as quickly as possible. The time window of 150ms has been computed in order to guarantee that the torque value corresponding to vehicle movement is not reached in every working condition. After $150 ms$ the EVP current is switched from I_{max} to I_{limit}, I_{limit} being the lowest value of the current that provides enough torque to move the vehicle, measured in different working conditions. This value of the EVP current is kept for another $150 ms$; then the closed-loop algorithm is activated. Notice that this strategy has been designed to guarantee that no torque overshoot occurs (as it is cause of driver's discomfort), at the price of a possible delay in reaching the movement torque.

3.2 Closed-loop control

The closed-loop control of the motion inversion is designed based on a dynamical model of the vehicle longitudinal dynamics (see also Savaresi et al. [2006]). Specifically, if we consider the dynamics of the vehicle in the longitudinal direction (described by the state variable ω_{out}), we can write a simple model of the form

$$J\dot{\omega}_{out} = \tau(I)T_e(\omega_{in}) - T_r, \tag{1}$$

where J is the vehicle inertia, $\tau(I)$ is the transmission-ratio, *i.e.*, $\tau(I) = \omega_{out}/\omega_{in}$ (note that τ is a function of the EVP current I, which is the control variable); we assume that the inner-loop which controls the EVP current is dynamically decoupled from this outer-loop. $T_e(\omega_{in})$ is the engine torque which, given a throttle position, is function of the engine speed $T_e(\omega_{in})$ only. Finally, T_r is the resistant torque of the whole vehicle, mainly due to friction. In principle, T_r should be a function of the vehicle speed but - for the sake of simplicity - we consider this torque as a non-measurable disturbance, which, within the motion-inversion speed range, is almost constant.

The nonlinear dynamical model (1) can be linearized around a working condition defined by $\bar{I}$ and $\overline{\omega}_{in}$. To this aim, if we define $\delta\omega_{out} = \omega_{out} - \overline{\omega}_{out}$, $\delta I = I - \bar{I}$, $\delta T_e = T_e(\omega_{in}) - T_e(\overline{\omega}_{in})$ and $\delta T_r = T_r - \overline{T}_r$, we obtain

$$J\delta\dot{\omega}_{out} = \tau'(\bar{I})T_e(\overline{\omega}_{in})\delta I + \tau(\bar{I})\delta T_e - \delta T_r, \tag{2}$$

where $\tau'(\bar{I}) := \frac{d\tau}{dI}|_{I=\bar{I}}$. Note that system (2) is characterized by a control input δI, a non-measurable disturbance δT_r, and a measurable disturbance δT_e.

In our previous work on motion-inversion control (see Savaresi et al. [2006]), the motion inversion control loop was designed as a regulation loop which controlled the vehicle acceleration, which was to be kept constant throughout the inversion. This was possible because in the prototype vehicle used in that work the motion-inversion was defined as a fully symmetrical maneuver, whose aim was to take the vehicle from a forward speed v to the opposite one $-v$, and the driver was not allowed to use neither the accelerator nor the brake during the motion-inversion. Unfortunately, this is no more the case in the tractor object of this work, as now the driver is allowed to both accelerate and brake during the inversion maneuver, thus making the motion-inversion a possibly non-constant-acceleration maneuver.

Accordingly, we had to recast the motion-inversion control into a tracking control problem, where the controlled variable is the output reverser speed ω_{out}. For this purpose, we designed a simple proportional controller which tracks a ramp-shaped signal ω_{out}. The decision of employing such a simple controller is twofold: first of all is due to the fact that - as the final purpose of the research is to implement an auto-tuning control system for the motion inversion - we want to keep the set of control parameters as small as possible. Secondly, a proportional controller has the advantage that, by monitoring the closed-loop error, one can detect a variation in the vehicle inertia and/or in the resistance torque T_r and can thus adapt the controller gain accordingly. As a matter of fact, both these parameter can suffer significant changes during the vehicle usage: the vehicle inertia J because of additional loads or trailers and the resistance torque T_r due (mainly) to road slope. As no additional sensors can be added due to tight cost constraints, the possibility of gaining additional information was so important that a simplification of the control architecture - at the price of possibly reduced performance - was preferred. Note, in fact, that if the linearized model (2) is controlled with a proportional gain k_p, the steady-state error with a ramp reference signal, is

$$e_\infty = \frac{J}{k_p(\tau'(\bar{I})T_e(\overline{\omega}_{in})},$$

while the steady-state error due to a step disturbance in the resistance torque T_r is

$$e_\infty = -\frac{\overline{T}_r}{k_p(\tau'(\bar{I})T_e(\overline{\omega}_{in})}.$$

Thus, by monitoring the steady-state error (recall that $\tau'(\bar{I})T_e(\overline{\omega}_{in})$ is known) one can detect variations in J and T_r and vary k_p to recover the desired performance.

An important issue is how to generate the reference signal ω^o_{out}: the initial speed employed when the closed-loop control begins is evaluated as the average speed over the last $100ms$ of the open-loop control phase. Then, the reference signal is generated as a constant slope ramp, but the slope can be adjusted on-line to account for the possible acceleration and braking which occurs during the motion-inversion. Note that the reference ramp is generated up to the opposite value of the initial inversion speed, but the controller is de-activated when the clutch engagement condition is verified (this can happen both above and below the target speed in the opposite direction due to acceleration and/or braking).

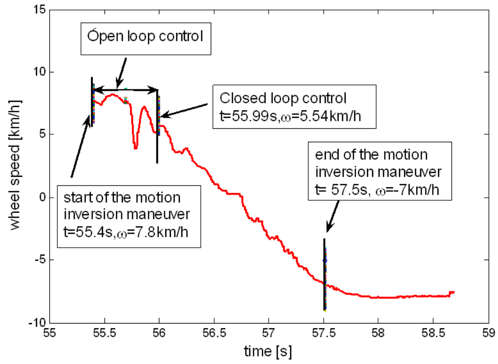
4. COST FUNCTION DEFINITION

Based on the previous description of the motion-inverter control system, it is clear that different design parameter concur to achieve a high quality maneuver. Specifically, the open-loop control is characterized by the following set of parameters:

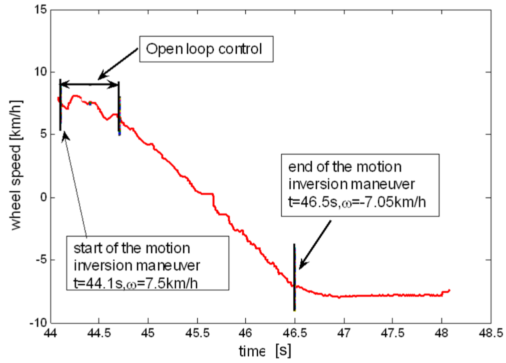
- I_{limit}: this parameter is crucial, as a too high value of I_{limit} implies that, when the open-loop phase is completed, the pressure in the clutch is higher than that ensuring movement, so that a strong deceleration causing discomfort is perceived by the driver. On the other hand, if I_{limit} is too low, the clutch is not engaged after the open-loop phase and this results in a longer inversion;
- Δt_1: it is responsible for the clutch filling (its value impacts on the inversion in the same way as does I_{limit});
- Δt_2: it represents the whole open-loop phase duration, estimated based on the hydraulic dynamics. It always showed to be appropriate in all the experiments, so that it does not appear to be crucial for the maneuver quality,

while the closed-loop control is simply characterized by the proportional gain value k_p. Even if the aim of this part of work is that of classifying the maneuver quality, the overall goal of the research project is that of designing an auto-tuner for the motion-inversion controller, so that - based on the output of the quality assessment phase - the required correction to the controller parameters can be provided to converge to a predefined quality level as the inversion maneuver is repeated by the user. This final system will, on one hand, rationalize the end-of-line tuning phase and, on the other, keep the controller tuned during the vehicle whole life (note that the working conditions for the tractor can highly vary due, for example, to road slope, loads, temperature, usage and so on).

Thus, it is advisable to design a cost function which - while measuring the maneuver quality - is also indicative of the controller parameter which is responsible for the lack of quality. To visualize difference between two extreme conditions, let us refer to Figures 7(a) and 7(b), the first showing the wheel speed measured in a motion-inversion labeled as *bad*, while the latter in one labeled as *good* (note that in this case the difference between the two is in the driver comfort rather than in the maneuver duration). As it can be seen, the wheel speed is indeed an informative signal to employ for comfort assessment: Figure 7(a) shows in fact much more significant oscillations in the wheel speed than Figure 7(b), both in the open-loop and in the closed-loop phase. As mentioned above, we will try to keep the information between open and closed loop phase separate, and this will lead to a 2-dimensional comfort indicator, one for each controller mode.



(a)



(b)

Figure 7. Plot of the wheel speed in a bad (a) and in a good (b) Forward→Reverse motion inversion.

4.1 Inversion duration

We now turn to describe in detail how we measure the motion-inversion duration, which is the first parameter that concurs to define the maneuver quality. The initial time instant at which the maneuver begins is easily assessed, as it is triggered by the driver's action on a lever. As for the final time instant, instead, it must be determined based on the evaluation of the actual engagement of the clutch which is active at the end of the inversion (*e.g.,* the Reverse clutch in a Forward→Reverse inversion). Clearly, an inversion maneuver can be requested at different vehicle vehicle speeds and - as the driver is allowed to accelerate during the maneuver - the clutch engagement can be achieved at a final speed different from the opposite of that at which the inversion began. Specifically, the clutch is said to be engaged when the engine speed ω_{in} equals the reverser output shaft speed ω_{out} (see Remark 4.1 for a discussion on this issue).

Accordingly, if no action is taken to normalize the inversion duration with respect to the engine speed, one would have different durations according to the initial and final speeds of the vehicle, which makes it difficult to correctly assess the maneuver quality with respect to this parameter.

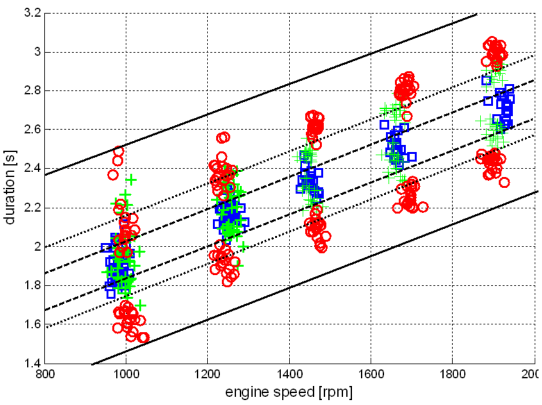


Figure 8. Classification of the motion inversions: maneuver duration as function of the engine speed: bad (circles), medium (+) and good (squares) inversions.

To appreciate this, refer to Figure 8, where the maneuver duration is plotted as function of the engine speed, and the different maneuvers are labeled with the driver quality assessment; that is: bad maneuvers (circles), medium maneuvers (+) and good maneuvers (squares), respectively. As Figure 8 shows, the obtained classification satisfactorily matches that provided by the human driver, and the three different degrees of quality (good, medium and bad) give rise to quite separated clusters. These are indicated in Figure 8 by the area within dashed lines for the good maneuvers, the area within dotted lines for the medium ones and the area within solid lines for the bad ones. Note that Figure 8 shows all the performed motion-inversions, whose quality depends both on duration and comfort. This explains why the bad and medium clusters exist both for larger and smaller durations than that of the good maneuvers one.

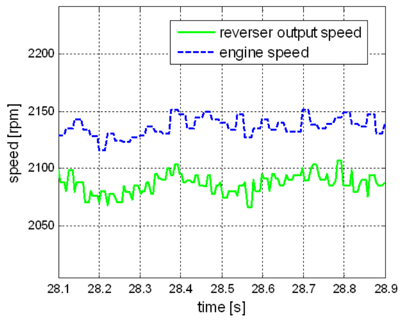


Figure 9. Plot of the engine (dashed line) and reverser (solid line) output speed with engaged clutch.

Remark 4.1. (clutch engagement). Note that we defined the clutch to be engaged when the engine speed ω_{in} equals the reverser output shaft speed ω_{out}. Nonetheless, even during constant motion, the two are not perfectly equal due to the geometry of the transmission, but they differ by a constant value (see Figure 9). Based on a large set of motion-inversions data we experimentally identified the relation between the two, which is of the form $\omega_{in} = \gamma + \kappa\omega_{out}$. Accordingly, we say that the clutch is fully engaged when the relation

$$\frac{\omega_{in} - \gamma}{\omega_{out}} = \kappa \pm 5\%$$

holds over a time window of $300\,ms$. The 5% width of the tolerance zone has been chosen according to the experiments and to the transmission characteristics.

Based on the above discussion, in order to obtain a significant and objective measure for the maneuver duration, it is necessary to express it in terms of *normalized time*; the final measure of inversion duration Δ_n is therefore computed as

$$\Delta_n = \frac{d - \mu}{\omega_{in_{IN}} + \omega_{in_{END}}}\ [s/rpm], \tag{3}$$

where $d\,[s]$ is the inversion duration, μ is the offset (which was experimentally identified based on all the inversion tests), $\omega_{in_{IN}}\,[rpm]$ and $\omega_{in_{END}}\,[rpm]$ are the initial and the final engine speeds, respectively. In what follows, the normalized inversion duration Δ_n will be employed.

4.2 Inversion Comfort

The second crucial attribute of a motion inversion is the driver comfort: the main cause of discomfort is due to large vehicle accelerations or decelerations which are mainly caused, on one hand, by a too large value of the open-loop parameter I_{limit} and, on the other, by a too high value of k_p. In order to capture the effects of these bumps, we need to compute the best possible approximation of the longitudinal acceleration experienced by the driver based on the available signals, recalling that both the open-loop and the closed-loop phases are responsible for the overall comfort of the motion inversion. As mentioned before, we want to keep the information of the two phases separated, so that the final cost function can provide also a direct indication of the controller parameters which have to be tuned to improve the driver comfort.

Let us start from the open-loop control phase: the comfort indicator is defined as

$$\mathrm{Var}\left[\frac{d\omega_{out}}{dt}\right]_{t\in\Delta t_{ol}}, \tag{4}$$

where $d\omega_{out}/dt$ is the numerically computed (and properly low-pass filtered) wheel acceleration and Δt_{ol} is the time interval in which the open-loop controller is active.

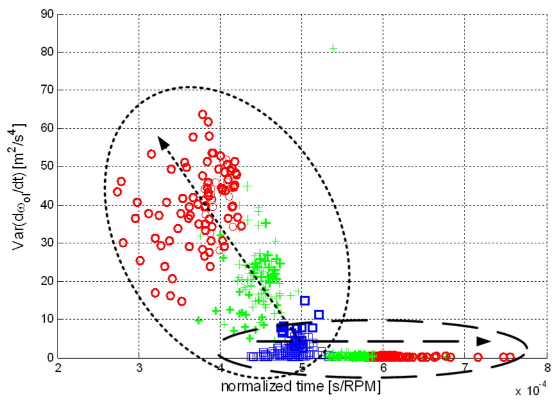


Figure 10. Classification of the maneuver comfort as function of the normalized inversion time based on the open-loop control phase: bad (circles), medium (+) and good (squares) inversions.

To evaluate the effectiveness of the indicator, refer to Figure 10, which shows the classification of the maneuver comfort as function of the normalized inversion time based on the open-loop control phase. Again, the different maneuvers are labeled with the driver quality assessment: bad maneuvers (circles), medium maneuvers (+) and good maneuvers (squares), respectively. As can be seen in Figure 10, the three different degrees of quality (good, medium and bad) are well separated. Correctly, as now we are evaluating both duration and comfort, two directions appear when moving from good to bad maneuvers: specifically, the performance degradation due to a long maneuver is highlighted with the dashed oval box in Figure 10 and evolves along the direction of the dashed arrow. Similarly, the performance degradation due to a discomfortable maneuver is highlighted with the dotted oval box in Figure 10 and evolves along the direction of the dotted arrow.

Turning to the comfort indicator for the closed-loop phase, it is defined as

$$\mathrm{Var}\left[\frac{de_{cl}}{dt}\right]_{t\in\Delta t_{cl}}, \tag{5}$$

where de_{cl}/dt is the numerically computed (and properly low-pass filtered) time derivative of the closed-loop error e_{cl} and Δt_{cl} is the time interval in which the closed-loop controller is active. Note that - as $e_{cl} = \omega^o_{out} - \omega_{out}$, de_{cl}/dt is nothing but the wheel acceleration during the closed-loop phase.

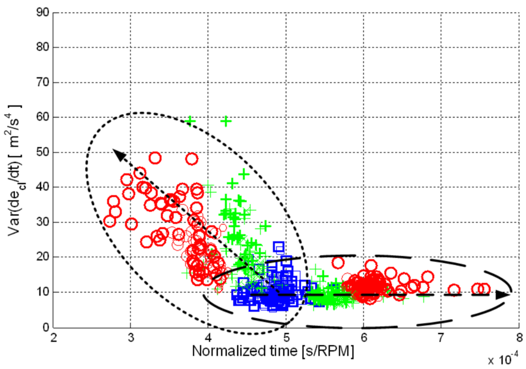


Figure 11. Classification of the maneuver comfort as function of the normalized inversion time based on the closed-loop control phase: bad (circles), medium (+) and good (squares) inversions.

The information yielded by this indicator is depicted in Figure 11, which shows the classification of the maneuver comfort as function of the normalized inversion time based on the closed-loop control phase. The different maneuvers are labeled as usual: bad (circles), medium (+) and good (squares), respectively. Again, as we are looking at a $2D$ cost function, we have that the performance degradation due to a long maneuver (highlighted with the dashed oval box in Figure 11) evolves along the direction of the dashed arrow, while the performance degradation due to a discomfortable maneuver (highlighted with the dotted oval box in Figure 11) evolves along the direction of the dotted arrow.

It is worth mentioning that, as the wheel encoder does not correctly measure speed values below $1\,km/h$, in the computation of the comfort indicators (4) and (5), the signal within $\pm 1\,km/h$ is disregarded.

The final results provided by the complete 3-dimensional cost function, *i.e.,* that obtained taking into account the maneuver duration, the open-loop phase comfort and the closed-loop phase comfort, are shown in Figure 12, where the comfort indicators are plotted as normalized variances to improve readability.

As can be seen by inspecting Figure 12 (where the maneuver label is the usual one), all the three dimensions of the cost function carry valuable information, and the overall definition of the maneuver quality correctly matches the driver perception. Moreover, as attention has been devoted to maximize the expressiveness of the cost function information and its relation to controller parameters, this work constitutes an effective step toward the design of an automatic tuner to be employed both for end-of-line purposes and for adjusting the controller behavior during the vehicle whole life.

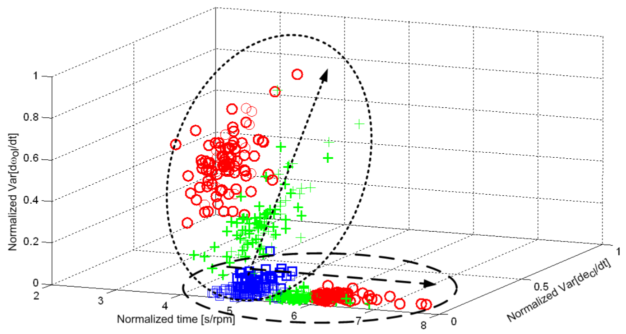


Figure 12. Complete classification of the maneuver quality in a 3-dimensional space: normalized time, open-loop and closed-loop comfort indicators. Bad (circles), medium (+) and good (squares) inversions.

5. CONCLUDING REMARKS AND FUTURE WORK

This work presented the estimation of the maneuver quality from measured data for an automatic motion-inverter in agricultural tractors. The results confirm the possibility to effectively classify the performed maneuver from measured data and to label it with a quality attribute that matches the one assigned by the driver. The overall goal of the research project is that of designing an auto-tuner for the motion-inversion controller, so that - based on the output of the quality assessment phase - the required correction to the controller parameters can be devised to achieve a predefined quality level as the inversion maneuver is repeated by the user. This final system will both help to rationalize the end-of-line tuning phase and to keep the controller tuned during the vehicle whole life.

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