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DEVELOPMENT AND IMPLEMENTATION OF A SHIFT ASSISTANCE SYSTEM FOR AN AUTOMOTIVE CHASSIS DYNAMOMETER

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Abstract. *Besides the powertrain, driver behavior and, more specifically, gearshift strategies are parameters which have a significant impact on the overall fuel consumption of a motor vehicle. In this context, the present work aims to describe the development and implementation of an acquisition system and a human-machine interface programmed in the visual programming language LabVIEW for the execution of standardized drive procedures on a chassis dynamometer. Additionally, this interface is provided with a gearshift indicator designed for the assessment of gearshift strategies on manual transmission vehicles. Different shifting patterns from previous works were then selected and deployed to evaluate their effect on the fuel economy when the test pilot performed the standardized NBR6601 drive cycle. This experiment intended not only to confirm the effectiveness of the Interface as a test driver assistance system but also to provide a measurement of how much of influence the introduction of a Gear Shift Indicator on the dashboard of the vehicle could have on fuel economy. This apparatus, which is already mandatory in the European Union since 2012 for newly produced vehicles, is intended to guide the decision-making of the driver and encourage him to take an eco-friendly approach regarding gear shifting, representing a low cost measure to reduce fuel consumption and consequently greenhouse gas emissions already in the current automotive fleet. From the tests, a variability of 29.8% in fuel consumption could be achieved when contrasting strategies focused on vehicle performance and on fuel economy, provided that the same drive schedule, i. e., same speeds as a function of time, was performed, proving the efficacy of the system as a communication platform from the vehicle engineers to the driver.*

Keywords: *Roller Chassis Dynamometer, Gearshift Strategy, Gear Shift Indicator, Human-Machine Interface, Experimental Validation*

1. INTRODUCTION

According to the last report presented by the Intergovernmental Panel on Climate Change, the transportation sector was responsible in 2010 for 14% of the anthropogenic Greenhouse Gas (GHG) emissions (Edenhofer, *et al.*, 2014). Moreover, it is difficult to forecast when electric vehicles are going to be a competitive substitute to conventional cars; projections indicate that by the year 2035 the market share of newly sold vehicles propelled by internal combustion engines is still not going to be halved (Orcutt, 2016). In the meantime, without an alternative in sight, large amounts of GHG are continuously being exhausted by the current fleet of vehicles.

Besides that, estimates from the International Council on Clean Transportation (Posada and Façanha, 2015) point that in some regions of the world most part of the newly produced vehicles is still being deployed with manual transmissions: 60% in China, the biggest automotive market in the world; 83% of the vehicles sold in the European Union and in Brazil; 98% in India. For this transmission design, the selection of the gear ratio depends mostly on the driver experience and on his subjective criteria, contrasting with automatic and automated transmissions for which gear ratios are optimally selected in a manner to provide good fuel economy and sufficient vehicle performance.

One way to mitigate this problem is offered by the introduction of a Gear Shift Indicator (GSI) into the dashboard of the vehicle, approach which is already mandatory since 2012 for all vehicles provided with manual gearboxes in the European Union (The European Commission, 2012). By employing this technique, the driver would not only be able to reduce its carbon footprint but also be economically benefitted by a decrease in consumption.

Academic research has already provided evidence of reduction in fuel consumption by employing this technique: Vagg, *et al.*, (2012) could show 9% of improvement in the urban scenario of the NEDC drive cycle; the same author (Vagg, *et al.*, 2013) then assessed the impact of a driver assistance system in light commercial vehicle fleets, resulting in 7.6% of average fuel savings; a report to the UK Department of Transport (Norris, *et al.*, 2010) also presented a reduction between 6.5% to 13.5% in fuel consumption in the urban excerpt of the NEDC drive cycle, if the driver is instructed when a gear shift must be performed.

In this regard, the present work intends to describe the development of an acquisition system and a Human-Machine Interface (HMI) provided with an emulated GSI for a chassis dynamometer. To comprove the efficacy of this system the NBR6601 drive cycle, which is based on the American FTP-72 standard, was executed four times and the speed profile performed by the driver was then compared with the one provided by the standard and its tolerances. Besides that, at each run, the driver employed a different gearshift policy, being one provided by the manufacturer of the vehicle and three extracted from the multi-objective optimizations performed by Eckert (2007). From these experiments, it was also possible to quantify how much of impact the technology of the GSI would be able to deliver on the fuel economy in order to mitigate part of the GHG emissions in current vehicles.

This paper is subdivided into the following sections: firstly, a description of the acquisition system developed to the present work will be described; secondly, the HMI which was built in the visual programming language *LabVIEW* to provide the driver with information regarding the drive cycle and the gear strategy (emulated GSI) is described; the fourth Section is dedicated to the description of the experiment itself; Section 5 lists the results obtained throughout the four executions of the drive profile; lastly, the conclusions of the present work are discussed.

2. THE CHASSIS DYNAMOMETER OF LABSIN

The Laboratory for Integrated Systems of the University of Campinas (LabSIn) possesses since 2013 an all-wheel drive twin roller chassis dynamometer originally intended to the assessment of the fuel and energy efficiency of vehicles equipped with alternative propulsion systems. However, its layout has been continuously changed to allow new test procedures, according to the necessities of the projects being developed in the laboratory. As an example thereof, Eckert (2017) coupled all the mechanical actuators of the dynamometer to the front axle to reduce the equivalent inertia of the rollers and to attenuate the losses produced by a belt transmission that used to connect the front to the rear axles. In this current configuration, the dynamometer was turned into a two-wheel drive for testing smaller front wheel drive urban cars. Figure 1 illustrates the equipment employed for the control of the test bed.

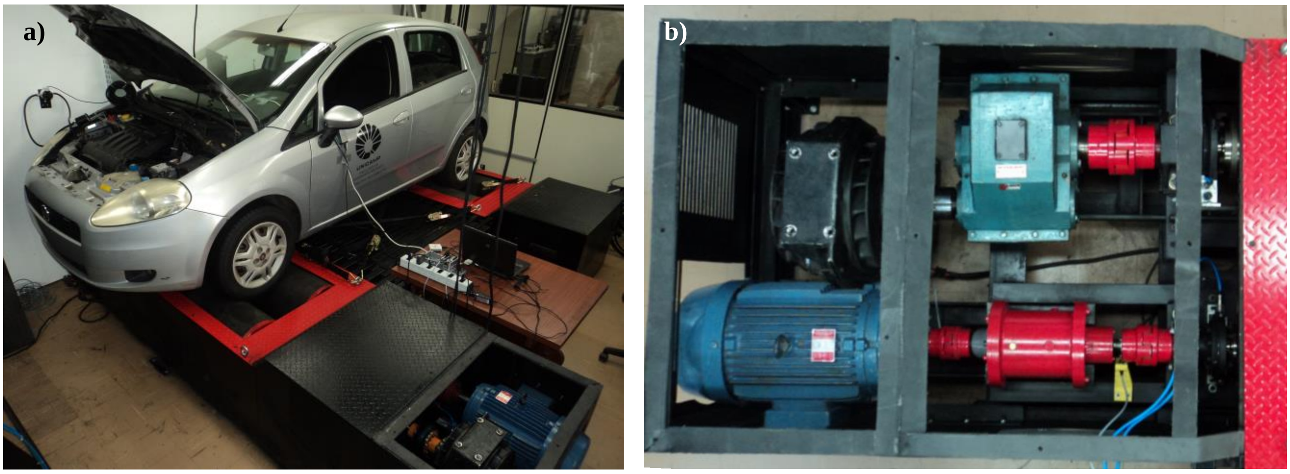

Figure 1: Pictures from the Chassis Dynamometer of LabSin. a) Test vehicle in position for the test; b) Detail from actuators, gear reducers, encoder and torque meters.

This paper focuses on the new development of an acquisition system and of an HMI, which was programmed in the visual programming language *LabVIEW* in order to increase the flexibility of the test bed not only in regard to layout changes but also to permit improvements in the sensor electronics. This way, the test bed can be more easily adapted to new measurement devices, actuators for specific applications and also can allow studies on the dynamics of each individual system, including the dynamometer itself. This section provides a description of the apparatus employed during the experiments.

2.1 Mechanical Layout

The tandem twin roller chassis dynamometer of LabSIn counts upon a 30 HP 2-poles induction motor (AC-Motor) for power inputs, an eddy-current brake (EC-Brake) for power absorption and four inertia rollers for energy accumulation. The AC-Motor is driven by a frequency inverter CFW701 from *WEG*, which can be controlled by either speed or torque reference by means of an analog 0-5 V input signal. In its turn, the EC-Brake is actuated by a single-phase power controller SPC1-50 from *Autonics* whose signal is then rectified by an SKB-72 power bridge rectifier from *Semipont*; in this case, an analogue 1-5 V input signal controls the portion of the cycle of the 220 VAC power supply which is rectified and sent to the poles of the retarder. Additionally, two gear reducers are employed to amplify the torque of the actuators at the rollers; friction brakes are only actuated if an emergency braking of the system is necessary. Figure 2 provides information about the layout of the equipment.

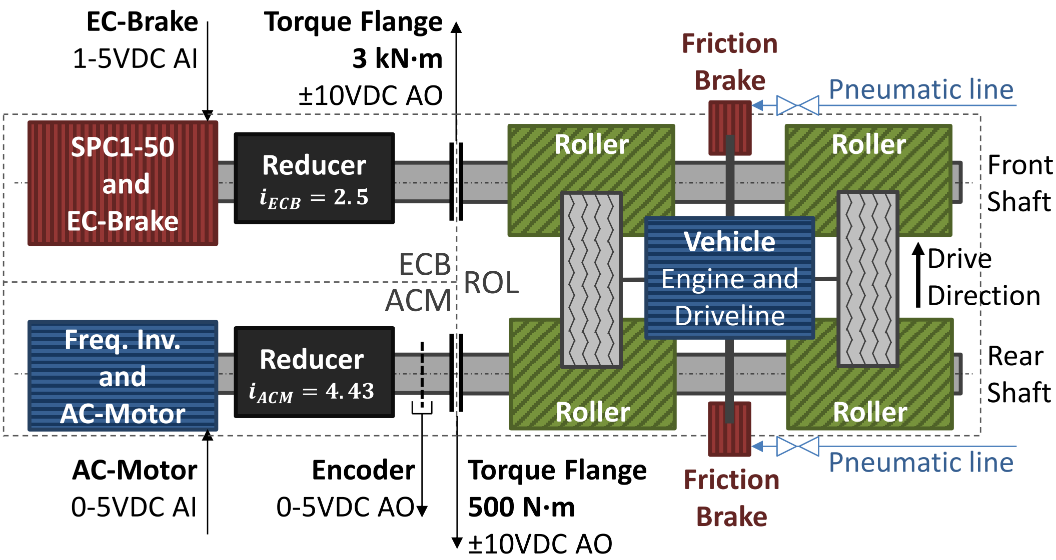

Figure 2: Schematic representation of the twin roller chassis dynamometer of LabSIn.

2.2 Sensors

Regarding the measurement apparatus, two universal torque transducers T40B from *HBM* (contactless torque flanges) were employed during the tests. One capable of measuring torques up to 500 N·m is placed between the reducer that is coupled to the AC-Motor and the rear rollers of the front shaft; the second torque measurement device with a range of 3 kN·m is placed between the reducer connected to the EC-Brake and the front rollers of the front shaft (see Fig. 2). For the measurement of speed, an optic encoder was developed to replace the old inductive sensor fixed to the rollers. This change allowed an increase in resolution from 8 to 60 pulses per revolution (PPR). For this application, an *OMRON* EE-SG3 Transmissive Photomicrosensor was employed; the measurement disc is placed next to the 500 N·m torque meter. Furthermore, the fuel line of the vehicle under test, a FIAT Punto 2008 with a gasoline 1.4-liter engine, was intercepted by a flow meter with the resolution of 2800 pulses per liter (PPL) of fuel. Two of the vehicle sensors were also intercepted for the generation of fuel consumption maps: the crank position sensor for engine speed measurement and the throttle position sensor to assess the power requested by the driver.

2.3 Acquisition System and Control Unit

The acquisition scheme was built for this study by applying a modular test system from *National Instruments* (NI), making the system more flexible for further developments. For that, all the signals collected by the previously described sensors were sent to a NI-cDAQ-9178 chassis connected to a NI-9239 analog-digital converter (ADC) capable of delivering a sampling rate of up to 50 kS/s/ch. For the acquisition of speed sensors (optical encoder and crank position sensor), the two PFI lines of the chassis were employed. These ports are able to connect the pulse signal coming from both sensors to the internal clock of the chassis, which can reach a speed of 80 MHz (National Instruments, 2015). This increases the precision of the reading of the encoder speed, by increasing the resolution of the time scale from 20.0 µs – if an analog input is used – to 12.5 ns. In other words, by employing this approach, the measurement of the speed may become at least 1600 times more precise than by employing analog input ports. The cDAQ-9178 is responsible for measuring the frequency of both pulse signals without the need of implementing further pre-processing methods.

All the data was then sent to a computer provided with the *LabVIEW* programming language via Universal Serial Bus (USB) and processed by the dynamometer HMI, which is further described in the following section. If the control loop of the HMI is active, the control output is delivered to the controller of both actuators (Frequency Inverter for the AC-Motor and Single-Phase Controller for the EC-Brake) via a NI-9263 digital-analog converter (DAC) module, which is able to reach a sampling output rate of 100 kS/s/ch. Figure 3 shows the acquisition scheme which was developed and applied in the present work.

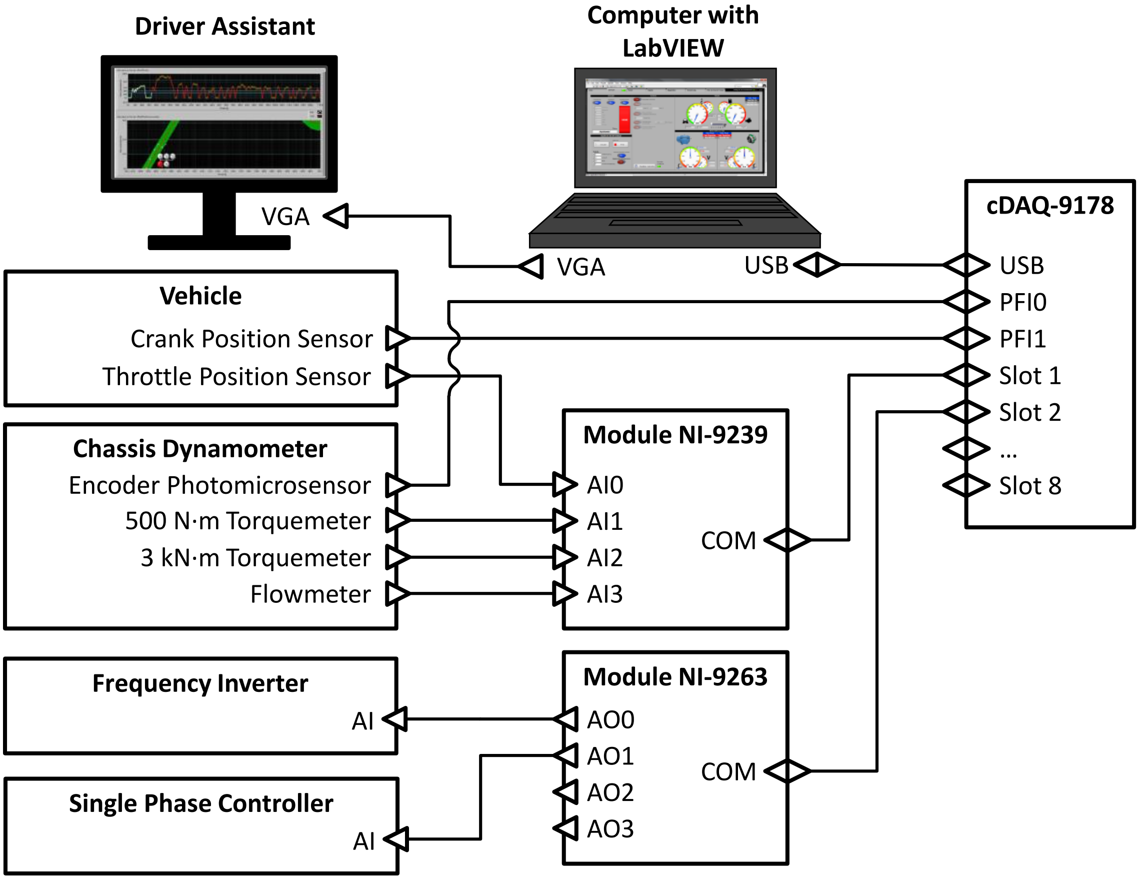

Figure 3: Schematic representation of the acquisition system deployed for the test bed.

3. HUMAN-MACHINE INTERFACE

As already stated, the HMI of the test bench was developed by the author in the *LabVIEW* visual programming language. The HMI attribution consists of providing a control panel to the operator, processing and logging data coming from the ADC and sending control inputs back to the EC-Brake and to the AC-Motor. Aiming to replicate driving resistances similar to that present on a real driving scenario, inertia compensation (Eckert *et al.*, 2017) and the emulation of aerodynamic drag were both included in its control algorithm (Bertoti *et al.*, 2017).

However, in order to assess the benefits of the implementation of a gear shift indicator, a second panel was developed so as to provide the driver with information about both the gear couple that should be selected at each instant and the speed profile that must be followed along the test. This visual interface was then shared by means of a computer screen placed inside the test vehicle, in front of the driver. Figure 4 depicts the screen presented to the operator of the dynamometer during the execution of the drive cycle and Fig. 5 shows the screen which was displayed to the test pilot.

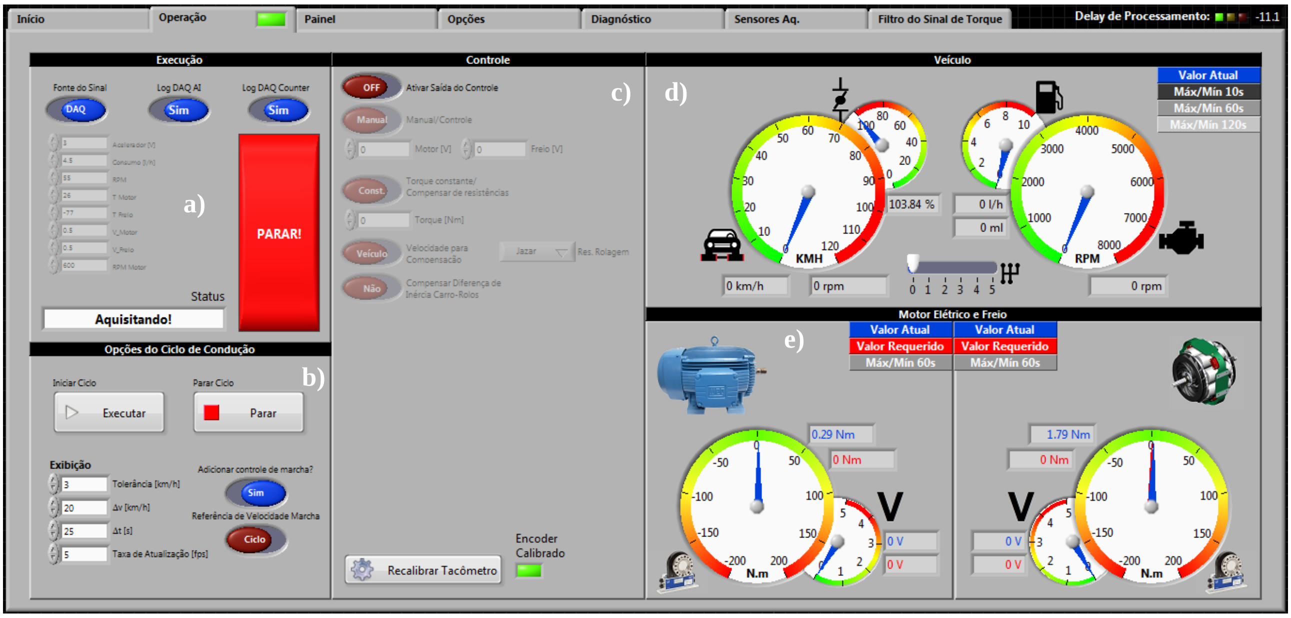

Figure 4: Snapshot of the screen presented to the operator during the tests.

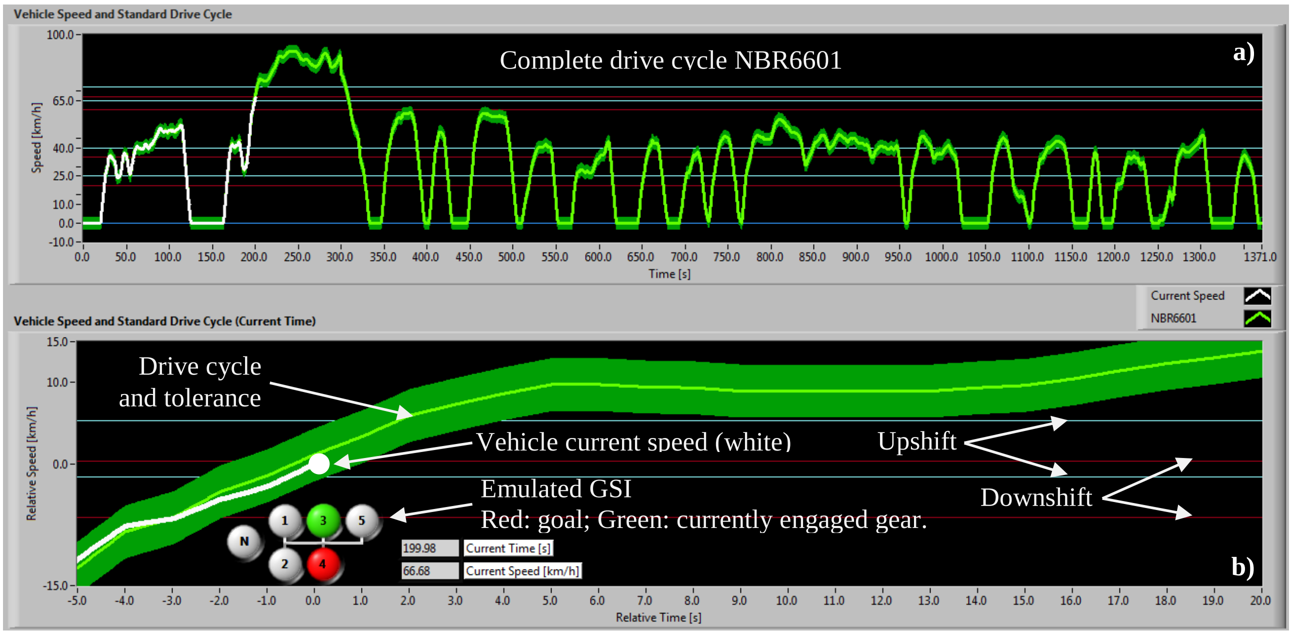

Figure 5: Snapshot of the screen presented to the driver during the tests.

In the first panel (Fig. 4), which is presented to the operator, one may find five different regions at the interface: region a) displays the status of the execution and has three switches, one to turn on the emulation of the sensor signal and two for toggling the data logging from the sensors on and off; b) controls the execution of the standard drive cycle and the appearance of the driver HMI; c) is employed to switch on and off the control loop and to provide options in regard to the control scheme – manual output, feedforward control, and road load compensations; d) shows information about the vehicle, as for example its current speed, throttle position, instantaneous and integral consumption, estimation of gear engagement, and engine speed; region e) shows information about the actuators, such as torque reading at the torque meter and reference control signal in volts which is sent to the cDAQ-9178 chassis. The gauges in this screen also plot maximum and minimum values reached in the last 10 s, 60 s and 120 s for the detection of possible instabilities during the operation.

However, a weakness of this arrangement must be taken into consideration. Since *Microsoft Windows*, being a general-purpose operating system, is not capable of granting a real-time operation (National Instruments, 2013), the HMI is not able to work at the same rate in which the data is collected by the ADC, given a continuous collecting of samples (fixed time step) and high sampling rates (more than 1 kS/s). To bypass this flaw, the HMI was set to work with sample buffers, which must be processed as a package for the synchronization with the longer length of time step of the HMI, reducing the probability of jitter. Normally the ADC is set to gather data at a rate between 2 to 10 kS/s, while the HMI can reach refresh rates from 20 to 50 Hz, meaning that the HMI must average packages ranging from 40 to 500 points per iteration. Besides that, by taking the mean value of many samples, the reliability of the measurements and of the control algorithm may also be improved, provided that this approach tends to attenuate noise.

Moreover, as a security measure for the system, if the Operating System starts working sluggish and a delay between the collected data and the processing time step is detected, the HMI stops running immediately, leaving the driver in charge for the complete stop of the dynamometer; if this happens, all control ports are automatically set to zero. The top right indicator in Fig. 4 is responsible to warn the operator in this regard.

For the driver, just the essential information about the drive cycle must be presented. In this case, as shown in Fig. 5, only two panels are depicted. Panel a) is static and displays the overall execution of the drive cycle, providing the driver also with future information about the next drive pulses. Panel b) is the main visualization of the execution of the cycle; it shows a window around the vehicle current speed and the current time step of execution, being this point (white dot) fixed in relation to the panel. Near this point, in a visible position, the test pilot has access to the emulated GSI, which plots both the currently engaged gear (in green) and the gear couple that should be engaged at the present time step (in red). The green curve shows both the speed at which the vehicle should be running, as well, as the acceptable range provided by NBR6601; the white line before the white dot depicts the history of the real speed of the vehicle, as read at the rollers. Furthermore, as a visual hint, the horizontal lines displayed in the background of both graphs represent the speed at which the driver must perform an upshift (blue) and downshift (red), demonstrating the gearshift strategy set in advance.

4. EXPERIMENTAL PROCEDURES

In his doctor Thesis, Eckert (2017) optimized the gearshift strategy for the same vehicle also for the NBR6601 drive cycle by means of a multi-objective genetic algorithm. Besides the strategy provided by the manufacturer (FIAT, 2008), three gearshift strategies were then selected from the Pareto frontier resulting from this optimization procedure: a strategy that minimized fuel consumption; a strategy which maximized the acceleration performance; a compromised solution for fuel economy and performance. Table 1 presents the upshift speeds ($V_{up,i\rightarrow i+1}$) and de downshift interval (ΔV_{down}), constant to all downshifts, characterizing each strategy.

Table 1 – Gearshift strategies employed during the tests (Eckert, 2017).

In km/h	$V_{up,1\rightarrow 2}$	$V_{up,2\rightarrow 3}$	$V_{up,3\rightarrow 4}$	$V_{up,4\rightarrow 5}$	ΔV_{down}
Standard FIAT	25.00	40.00	65.00	72.00	5.00
Min. Fuel Consumption	14.73	28.33	41.70	74.33	7.32
Best Performance	26.81	52.97	72.97	75.77	5.74
Trade-Off Strategy	19.95	33.91	57.38	75.49	7.40

The following equation provides the downshift speed from the $i+1^{th}$ gear to the i^{th} ($\mathrm{V_{down,i+1\rightarrow i}}$) by means of the upshift speed from the i^{th} to the $i+1^{th}$ gear couple ($\mathrm{V_{up,i\rightarrow i+1}}$) and the downshift interval $\mathrm{\Delta V_{down}}$.

$$\mathrm{V_{down,i+1\rightarrow i} = V_{up,i\rightarrow i+1} - \Delta V_{down}} \quad (1)$$

Applying these rules to the standard drive cycle and considering that the engine is in idle when the vehicle stops, one may come to the frequency plot for engaged gears shown in Fig. 6. From this figure, it is noticeable how the engaged gear couple may vary independently from the speed profile, which can be considered the same for all four executions. This consequently changes the operating point of the engine by forcing it to work in a more efficient region or at a position in the engine map where the driver has more power at disposal for steep acceleration. Consequently, for the Minimum Fuel Consumption strategy the 4^{th} gear is the most accessed, while for maximum performance, the second gear is employed along almost 50% of the 23-minutes-long drive cycle.

These strategies were then deployed as input parameters for the HMI, setting the shifting speeds displayed at emulated GSI which must be reproduced by the test driver during the execution of the drive cycle. It is necessary however to remark, that both the dynamometer and the vehicle engine were warmed up before the tests, contrasting with the exigencies of the standard, which demands a cold start. The heating of the whole system was performed, due to the fact that the vehicle cannot be easily removed from the test bed, whose lubricants must be heated for two hours in order to stabilize the viscous friction. In other words, the procedure was not able to follow strictly the requirement of the emission standard NBR6601 (ABNT, 2012). Only the speed profile was reproduced for the evaluation of fuel consumption.

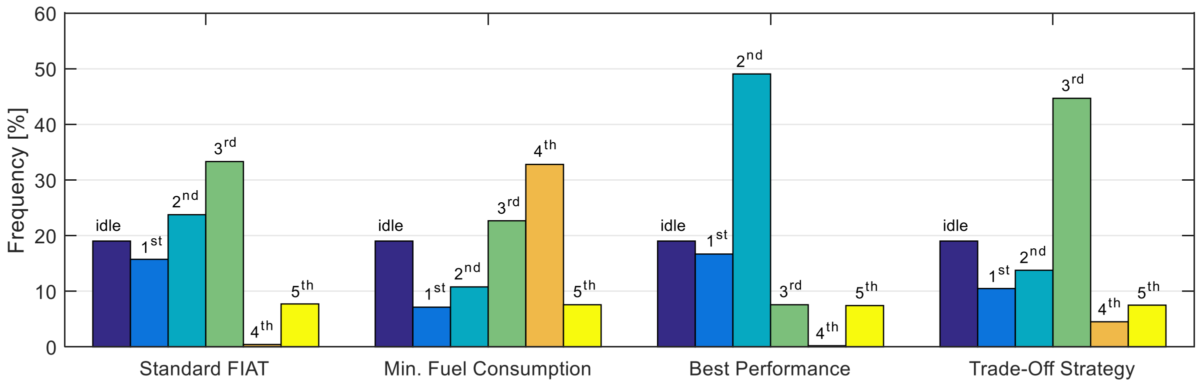

Figure 6: Frequency plot for the gear engagement along the NBR6601 drive pattern, employing the four different described gearshift strategies.

The four tests were performed to achieve two main goals: firstly, to verify if the HMI is capable of providing the driver with enough information to the execution of the drive cycle; secondly, to evaluate the variability obtained in fuel consumption when different gearshift policies were executed and, consequently, assessing the efficacy of having a GSI influencing the decision-making of the driver.

5. RESULTS AND DISCUSSION

Figure 7a shows the speed profiles of all four runs in comparison with the NBR6601 drive cycle for the interval between 150 s and 340 s of the test – when the vehicle reaches the top speed of 91.2 km/h. The shaded area represents the tolerance provided by the standard, *i.e.*, the vehicle speed at a given time must be contained inside an interval, which is defined by subtracting 3.2 km/h from the minimal speed inside a time interval of ±1 s counted from the current time and summing 3.2 km/h to the maximum value inside the same time interval. There are two exceptions to this rule: no deviation from the previous rule should last more than 2 s; if the vehicle speed breaks the lower boundary for longer than 2 s, the engine must be at full throttle (ABNT, 2012). This last situation may happen after a gear change to a high gear, as can be seen in Fig. 6 between the interval of 195.0 s to 201.8 s (Fig. 7b) for the Minimum Fuel Consumption Strategy after the driver changed to a 4^{th} gear when reaching 41.7 km/h. This moved the operating region of the engine to a lower speed, at which point the engine cannot supply the required power to fulfill the power demand for the high acceleration required by the test cycle.

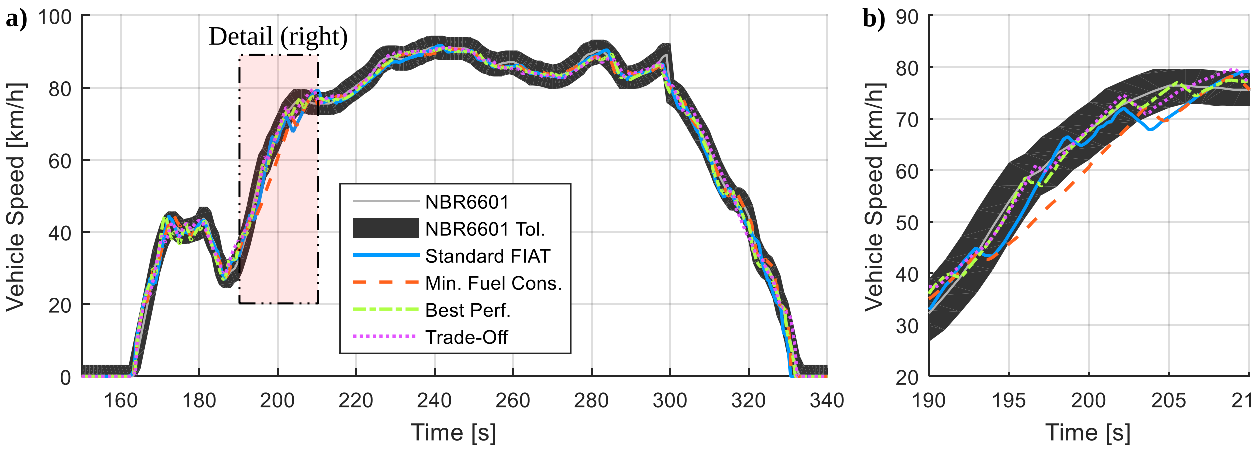

Figure 7: a) Excerpt and b) Detail of the speed profile executed by the test driver as a function of time for all four test runs. The standard drive cycle and its tolerances as provided by NBR 6601 are also shown as a reference.

In spite of this small deviation from the drive cycle, it can be seen from Fig. 7 that the driver was able to perform the rest of the drive cycle without much effort. As another proof of this statement, Table 2 lists the root mean square error (RMSE) and the standard deviation of the speed error for the execution of the drive cycle by the test driver for each of the four strategies. The maximal value for the RMSE occurred for the execution of the strategy for best performance. This is due to the fact that the vehicle acceleration becomes more sensitive to small steps at the throttle pedal when applying lower gears. This result was already expected when applying this strategy, since, without taking the idle time into consideration, 81.19% of the cycle was performed employing either the first or the second gear ratios. In contrast, the vehicle presented itself more controllable when the Minimum Fuel Consumption Strategy was performed, resulting in the lowest RMSE of the set. The same pattern is seen for the standard deviation of the error.

As a comparison, the RMSE for the lower and higher boundaries of the tolerance region are respectively 4.64 km/h and 4.96 km/h, meaning that the driver was able to keep the speed of the car mainly in an even narrower gap. From these results, it is possible to infer that the HMI is effective in its goal of assisting the driver during the execution of the drive cycle since the driver was able to reasonably follow the speed recommendation presented on the screen.

Table 2 – Standard deviation of the error and root mean square error between the NBR6601 standard cycle and the speed executed by the driver during each test run.

	Standard FIAT	Min. Fuel Consumption	Best Performance	Trade-Off
Std. Dev. of the Speed Error [km/h]	2.29	2.17	2.43	2.27
RMSE of the Speed Error [km/h]	2.34	2.20	2.46	2.31

In regard to fuel consumption, Figure 8 shows the trend line for the total fuel consumed from the beginning of the test until a given time, if different gear shift strategies were employed; Table 3 lists the total, as well as the mean consumption along the 12 km of the NBR6601 drive cycle.

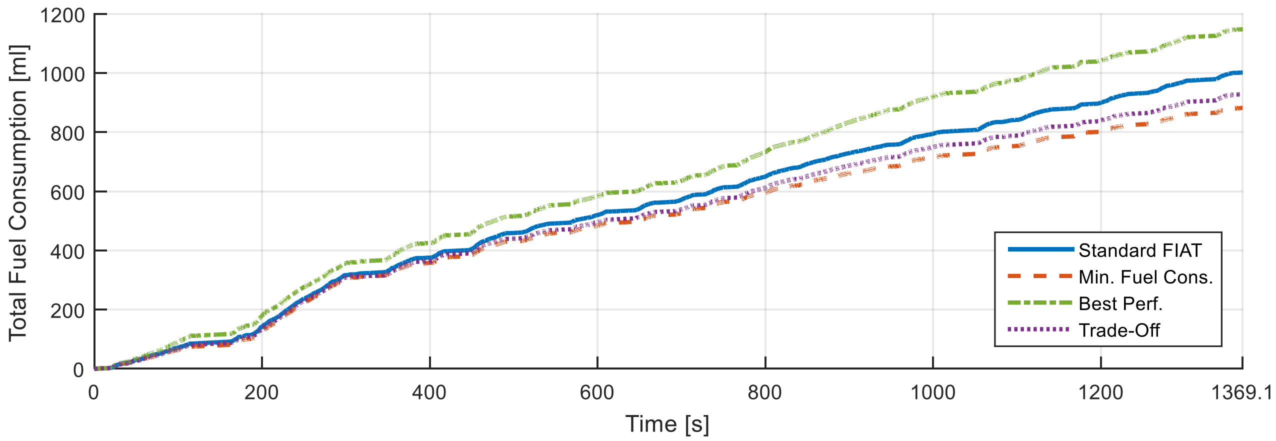

Figure 8: Fuel consumption obtained along the NBR6601 drive cycle for the different gear shift strategies.

Table 3 – Total fuel consumption and total traveled distance for the different shift strategies.

	Standard FIAT	Min. Fuel Consumption	Best Performance	Trade-Off
Total Fuel Consumption [ml]	1001.80	882.31	1148.20	928.28
Mean Consumption [km/l]	11.82	13.41	10.33	12.76
Total Travelled Distance [km]	11.838	11.858	11.861	11.846

One may notice from the presented results that a gearshift strategy that focuses only on acceleration performance may present 29.8% more fuel consumption along the NBR6601 drive cycle than a strategy optimized to deliver the maximum fuel economy. This agrees with the results obtained by Eckert (2017) who achieved a variability of 28.5% when comparing both strategies in his simulations.

This variation in fuel consumption when executing the same drive profile, neglecting the small periods of time when the engine was not able to deliver the required torque, represents a positive evidence that an improper or ill-advised shifting strategy may lead to higher fuel consumption, and consequently higher GHG emissions, without delivering advantages to the driver. Table 2 shows that the total traveled distance differs in less than 23 m (less than 0.2% of the traveled path) in the exact same 1,371 seconds when comparing all four strategies.

In other words, a Gear Shift Indicator could be of great help in molding the attitude of the driver in regard of gear shifting, reducing both GHG emissions and expenses with fuel. Furthermore, a compromised shifting strategy suited to the path to be performed by the driver could deliver almost 8% of improvement in fuel consumption, when compared to the standard strategy provided by the manufacturer, without losing much of acceleration performance. This result illustrates how an adaptive algorithm could be deployed in the GSI system to improve fuel economy in all the different drive scenarios to which the vehicle could be submitted.

6. CONCLUSIONS

The main goal of the present work was to deploy a Human-Machine Interface capable of providing both the operator and the test driver of the chassis dynamometer of the Laboratory for Integrated Systems of the University of Campinas with sufficient information throughout the execution of standardized drive cycles. With the working HMI, the authors were also able to assess how much improvement in fuel economy the installation of a Gear Shift Indicator in the dashboard of a vehicle would be able to deliver.

In order to achieve these objectives, the mechanical layout of the system was simplified by the decoupling of the rear rollers and the connection of both actuators (an induction motor and an eddy-current brake) to the front axle of the dynamometer, which was originally a four-wheel drive. Also, new measurement devices were installed: two contactless torque transducers from *HBM*, a 2800 pulses per liter flow meter and a 60 pulses per revolution encoder. Moreover, the acquisition system of the dynamometer was completely redeveloped by employing a modular data acquisition system from *National Instruments*, the cDAQ-9178. This apparatus has two main duties: firstly, to digitalize the analog data measured by the sensors at a significant time rate and send it to the computer where the HMI is running; secondly, to send the processed control effort back to the actuators.

As a final step, an HMI was built by employing the visual programming language *LabVIEW*, which led to the benefit of increasing the flexibility of the system, provided that the code is open for further development and testing procedures. In its current state, the HMI is capable of: controlling the eddy-current brake for road load compensations; of efficiently providing the operator with relevant information about the dynamometer test procedures; of assisting the driver during the execution of a standard drive cycle by showing him the current speed of the vehicle, the speed at which the vehicle should be running and the gears that should be and currently is engaged.

To validate the HMI, four test runs of the NBR6601 drive cycle were executed and the registered speed curves performed by the test driver were then compared to the standardized speed profile and the tolerances provided by the norm. From this first set of results, it was noticeable that the driver was capable of following the drive cycle with good precision, being the maximum root mean square error 2.46 km/h, which is almost half of the values obtained for the lower and higher boundaries of the tolerance range, 4.64 km/h and 4.96 km/h, respectively. During all runs, the tolerance rules provided by the norm were respected, demonstrating that the HMI is effective in its objective of assisting the driver during the executions of the drive profile.

Additionally, in each of four test runs, the gearshift strategy was also varied. For that, the four different gearshift strategies identified by means of a multi-objective optimization process from previous works were employed: the first is the strategy provided by the manufacturer; the second was the strategy which delivered the minimum fuel consumption in the simulations; the third policy provided the best performance (least lack of torque); the last strategy was identified by the optimization algorithm as the best trade-off between performance and fuel consumption.

From the fuel consumed in each test, it is possible to infer that different driver behaviors have indeed significant impact over fuel consumption since almost 30% of variability has been found. It is interesting to point out that the same drive cycle with the same range and duration was performed, independently from the employed strategy. Therefore, it was noticeable from the present work how a communication interface could positively interfere in the decision-making of the driver, providing him with online optimized information and serving as a communication platform between the designer and the driver.

In an overall conclusion, the implementation of a gear shift indicator in the current fleet of vehicles could be an inexpensive solution for providing additional fuel economy without taking completely away the autonomy from the driver, if performance is needed. Furthermore, these experiments reveal that a single gearshift strategy, such as the one provided by the manual of the each vehicle, when employed in all possible drive scenarios could lead to suboptimal fuel economy and that the GSI could be intelligently connected to the measurement apparatus of the vehicle, in order constantly adapt the recommended gearshift strategy to the current drive scenarios and to the driver. In resume, the implementation of a GSI in the dashboard of the vehicle could lead to substantial improvements in the fuel economy even in the current fleet benefiting not only the owner of the vehicle but also the environment, provided that the emission of greenhouse gases also decays with the improvement in fuel consumption.

7. ACKNOWLEDGEMENTS

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