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MEASUREMENT METHOD AND DEVICE FOR VEHICLE DYNAMICS

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Abstract: *This paper gives an overview of the initial development of dynamic parameters measuring system and method for vehicles. Mobile robotic platforms and vehicles driving abilities in real environment conditions are characterized and compared based on parameters that are measured during real world condition tests. The measuring results are used for comparison, development and improvement of vehicle platforms in their design stage.*

Key words: Real-time measurement, mobile robotics, vehicle dynamics.

1. INTRODUCTION

Different vehicles driving performance can be compared between each other based on real condition measurements while recording their position and acceleration performance during time test. Real-time data measured during driving reflects the real world and are essential to verify dynamic simulations [1] or tests with dynamometers. Same data can simultaneously be used for tuning engine, transmission and suspension parameters. If the vehicle is unmanned, the driving algorithms decision-making abilities, flexibility and versatility can be evaluated. In opposite case, the driver skills can be improved and rated.

The most important measure of dynamical performance is driving acceleration that can be measured at minimum with inertial navigation system (INS) and speed or position can be calculated. Usually additional parameters like power, torque, driving loss estimation, gear change and wheel slippage are needed for vehicle performance improvement. These parameters are usually not directly calculated. The current research introduces the method and device which enables to measure the vehicle acceleration and calculates additional parameters, based on the measured acceleration in real-time.

There are some devices available in market intended for simpler car performance testing, but have usually specific one-purpose functionality. Developed device [2] with novel measuring method is aiming to cover wide range of dynamic parameter measurements either an ordinary car or unmanned vehicle.

2. FRAMEWORK

The research is a part of general mechatronic system design methodology framework [3]. The framework is a new approach featured by the model-based architecture. This research provides the simulation algorithms, which are developed and verified on the different types of vehicles, starting from conventional cars to hybrid mobile robots. The measurement method and results are unified to general mobile vehicle and will be used as a part of simulation library of the design framework.

The target device of ongoing research is the mobile robotic platform, but the method and device can be fully used for any vehicle. The result of this research plays important role of verifying the mobile robot simulation algorithms and are used to develop autonomous navigation scenarios [4] of robotic platforms.

3. CALCULATION METHOD

Usually the position in INS is calculated using trigonometry and matrices, but this is complicated to compute [5] and does not solve automatic driving direction determination.

The acceleration of observed vehicles must be measured for every direction. The most important is longitudinal driving acceleration, which represents the maximum driving performance provided from engine or motor of a vehicle. The transversal acceleration is important for curved trajectory and vertical for observing suspension characteristics. All these acceleration directions assigned from vehicles body, must be separated and calculated from three-axis accelerometer data. As the measuring results are greatly affected of sensor positioning, data has to be transformed so, that the position does not affect measuring results. To find the direction of the sensor axes using gravity g_0, the mounting position detecting algorithm is implemented (Figure 1). If the device is fixed into a vehicle, at first the axis quiescent values $a_{q(x)}$, $a_{q(y)}$ and $a_{q(z)}$ should be found with averaging and data recorded during test $a_{t(x)}$, $a_{t(y)}$, $a_{t(z)}$ is reduced using them. Using only gravity, the plane T_h can be found, where longitudinal and transversal acceleration vectors are located. Distinguishing them is possible after the driving test data is recorded and maximum velocities $v_{\max(x)}$, $v_{\max(y)}$ and $v_{\max(z)}$ on each axis are obtained with integrating acceleration data. Therefore the coefficients K_v for each axis can be calculated, which represents their positioning level in driving direction:

$$K_{v(x)} = \frac{v_{\max(x)}}{\sqrt{v^2_{\max(x)} + v^2_{\max(y)} + v^2_{\max(z)}}} \qquad (1)$$

As the axes of a sensor will form a sphere, the summarized acceleration vector for driving direction can be calculated for each time stamp:

$$a_t^{\Sigma} = x_t \cdot K_{v(x)} + y_t \cdot K_{v(y)} + z_t \cdot K_{v(z)} \quad (2)$$

Also the acceleration data obtained from controller analogous-digital converter (ADC) must be transformed into real world units. The sensor axes values corresponding to natural acceleration $a_{1g(x)}$, $a_{1g(y)}$, $a_{1g(z)}$ can be measured by turning sensor 180° in each axis direction and also calculating zero acceleration levels $a_{0(x)}$, $a_{0(y)}$, $a_{0(z)}$.

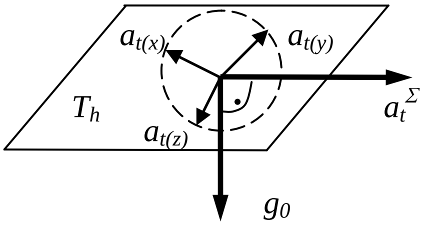

Fig. 1. Driving direction acceleration a_t^{Σ} is calculated from gravity and sensor axes measurements.

If only inertial measuring system is used, velocity v_n and position s_n data for each time stamp t_n can be calculated from acceleration with simple integration:

$$v_n = \sum_{i=1}^{n} a_n \qquad (3)$$

$$s_n = \sum_{i=1}^{n} v_n \qquad (4)$$

As engine and suspension driving vibration greatly affects the measuring results, digital filtering is needed. For dynamic data, the Kalman filter is suitable. It can be much simplified for faster computing without losing usability and not to filter out gear changes (Figure 2). During each time bit, the data can also be measured several times and averaged before saving into memory.

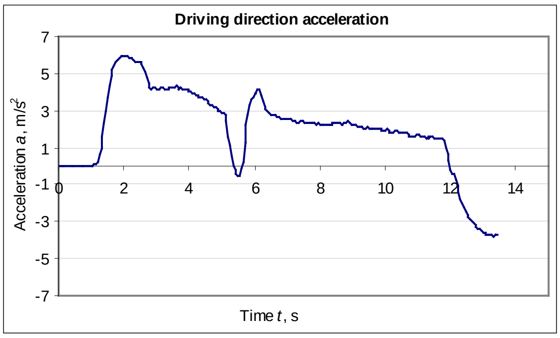

Fig. 2. Example of filtered acceleration data (car acceleration with one gear change).

It is also necessary to record engine turning frequency ω. It can be measured with timer from switching fronts of ignition coil or injector or with encoders in electric motors.

The power and torque for accelerating vehicles body mass can be calculated from acceleration. As These are related to vehicles mass m, acceleration a and time bit mean velocity $\bar{v}$, the body must be weighted. The power P at any given time stamp can be calculated from equation:

$$P = m \cdot a \cdot \bar{v} \qquad (5)$$

It is possible to record vehicle deceleration $-a$ after attaining given speed and therefore estimate summary losses from air, rolling, transmission etc. resistances. The resistive power P_t for vehicle acceleration is:

$$P_t = m \cdot (-a) \cdot \bar{v} \qquad (6)$$

As the resistive force F_t is growing with velocity square and therefore the trendline for describing it can be calculated with root mean squares method. If both powers are recorded, the summary power available from engine output can be found:

$$P_\Sigma = P + P_t \qquad (7)$$

and summary loss is:

$$\Pi = \frac{P_t}{P_\Sigma} \qquad (8)$$

If the engine turning frequency ω is also recorded, accelerating torque can be calculated from power P:

$$T = \frac{P}{2\pi \cdot \omega} \qquad (9)$$

The resistive torque can similarly be found. One of the most interesting and novel issues accomplished by the developed measuring method, is a gear changing parameters calculation. The gear change duration is calculated based on acceleration data for manual gearbox equipped vehicles and based on engine turning frequency for automatic gearboxes.

Another novelty is to measure vehicles summary clutch and accelerating wheels slippage. It is possible while comparing the accelerations of a vehicle body and engine turning frequency and is important for traction or suspension and driver skills or driving unit maximum performance improvement.

Several another sensor data can be fused into measurement process to find parameter correlation factors and to improve them from dynamic performance aspect. These are for example inner combustion engine parameters – lambda, manifold pressure, inner temperatures, ignition and injection parameters.

4. MEASURING ACCURACY

INS is acceptably precise for about under 15 seconds measurement tests, but it can much be improved with GPS correction on longer tests. Integration from acceleration measurements for velocity and position acquiring is also constantly increasing their error [6]. With only inertial measuring systems it is also important not to encounter constant velocity.

Another aspect is vehicle body deviation compared to wheels, while starting driving. Although inner combustion engine adds more noise and vibration into measurements (ignition wires, generator), electric motor have also negative electromagnetic effects.

Other sources of unavoidable errors have effect on test repeatability, but not for calibration procedure as they have equal impact on etalon device. Unknown error is added from driver or driving system behaviour, which yields to different results on same testing track. Engine temperatures are also varying while driving and therefore output power. Other errors are from real world counteractions, like variable wind, air temperatures and track properties. These effects can only be minimized if tests are carried out quickly or conditions measured.

All measurements that are calculated based on acceleration data, are dependent from constant parameters for given measurement – natural acceleration g, quiescent acceleration a_q, zero-acceleration level a_0 and the measure on natural acceleration a_{1g} for each sensor axis. The errors of these constants can be minimized with careful sensor calibration procedures. The other variables are measurement time t, all accelerations up to given time a^t and engine turning frequency ω. The power P and torque T is affected from most variables involved in measuring system:

$$P = f(t, g, a_0, a_{a1g}, a_{1g}, a^t, \omega) \qquad (10)$$

Calibration method is based on measuring the same object with etalon device [7] (Figure 3). The etalon device can be infrared laser based timing system installed into suitable length road track. The timing system is more accurate when measuring elapsed times with vehicle wheels interrupting infrared beams. However the errors are here uncertainty of track length, sensor positions and starting point as it can vary to length of wheel diameter.

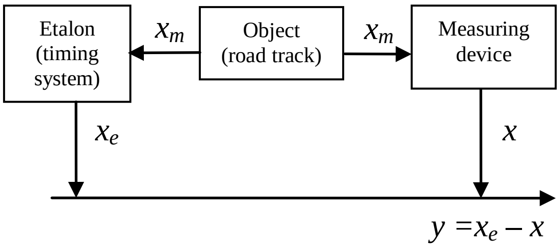

Fig. 3. Device calibration model.

5. MEASURING EQUIPMENT DEVELOPMENT

For testing and improving measuring method, the practical electronic device was constructed for carrying on tests in real world conditions on different vehicles.

As the microelectronics is constantly evolving, the great measuring, recording and computing capacity can be packed into very small mobile phone like device (Figure 4).

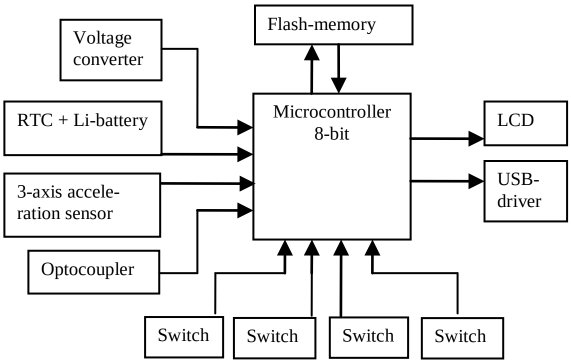

Fig. 4. Testing device block-diagram.

The initial version of a testing device is based on AVR 8-bit microcontroller working on 19.6608 MHz frequency, ± 19.6/58.9 m/s^2 MEMS acceleration sensor with 12/16-bit ADC, backlighted LCD and an optocoupler. The data is recorded on 20 Hz frequency to 1 MB flash memory. For giving time stamp to each measurement, the real-time clock (RTC) unit with rechargeable Li-battery is used. Optocoupler is used for measuring engine revolutions, which enables to calculate the torque of driving wheels. The recorded data can be transmitted to PC via USB.

The whole device (Figure 5) was made very light and small and is therefore mountable to any vehicle starting from motorcycles or small robotic platforms.

Fig. 5. Testing device finished.

6. EXPERIMENTAL RESULTS

Practical examples with the developed device for testing measuring method were carried out with regular cars.

The testing ensured that the developed position correction worked with good results. Table 1 shows, that even mounting the device at different positions only small deviation arise.

X / %	*Y* / %	*Z* / %	v_{calc} / km/h
0	0,8	99,2	61
0	3,1	96,9	61
0	45,0	55,0	62
0	-28,8	71,8	62
-9,5	-13,3	77,2	61
0	42,5	57,5	61
0,9	36,2	62,9	62

Table 1. Calculated speeds from acceleration with different device positions.

For attaining different speeds and measuring track length elapsing times, the device showed good repeatability 1 – 2 % depending on driver's success. The results were comparable with laser timing system results being different under 2 %.

Experimental results of calculated parameters are shown on the Figures 6-9.

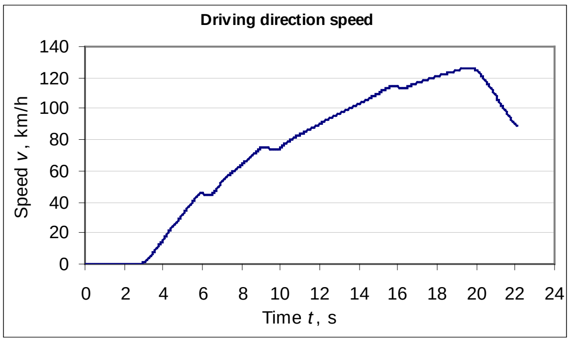

Fig. 6. Calculated car speed with gear changes (Audi S2 '94).

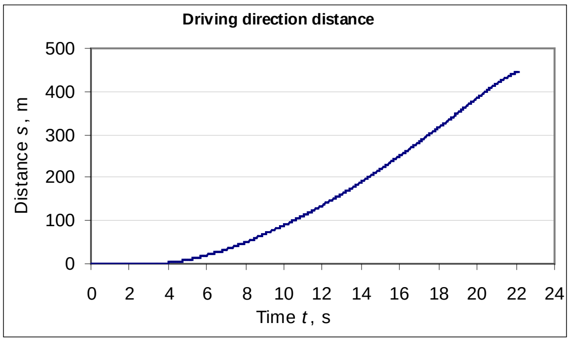

Fig. 7. Calculated car covered distance.

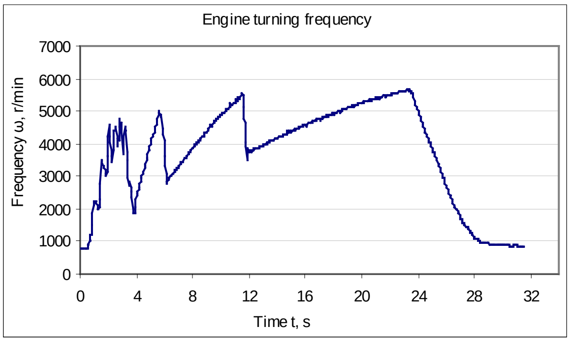

Fig. 8. Recorded engine turning frequency.

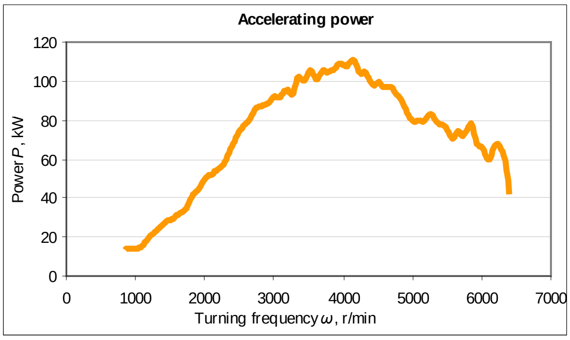

Fig. 9. Calculated accelerating power depending from engine turning frequency.

7. FUTURE DEVELOPMENT

The research has so far had a practical output for finishing first testing device and having also good opportunity to become commercial product. For testing equipment development, the GPS module will be involved for position correction. The data of the sensors will be fused together for improved acknowledgement of vehicles dynamics simultaneously involving other sensors data (temperatures, pressures, voltages). For vehicles where enormous noise and harness is usual, the CAN interface for sensor network is suitable for measurement accuracy improvement. If it is also needed, even greater computing and recording capacity can be implemented using 32-bit microcontroller and Secure Digital (SD) flash memory cards. According to the result of using the method and device with conventional cars the solution will be adapted to the unmanned robotic platforms. The measurement method will be further developed to implement it for vehicles with different moving methods, enabling to acquire real data of the specific robot platform and compare it with results of simulations. This enables to improve the simulation algorithm in library and prove its compatibility with real situation.

8. CONCLUSION

As a conclusion, the suitable measurement method basis for both manned and unmanned vehicle dynamics was developed and successfully tested. The method accomplished automatic position correction and driving direction sensing algorithms, which are essential for reliable measurement. The method enables to acquire many different characteristics for comparing vehicles or tuning their driving abilities. The development succeeded to practical testing device that is capable for accomplishing given tasks with good results.

9. ACKNOWLEDGEMENT

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