New concept of WIM system for urban traffic monitoring

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Abstract. Weigh-in-motion (WIM) sensors allow to estimate the static force applied on each wheel, respectively on each axle of the vehicle, as well as the total weight of the vehicle, based on the measurements made in dynamic mode, usually without disruption to traffic. WIM stations are complex systems which can use a lot of sensors for: measuring speed – inductive loops and radars; detecting the presence of axles - electromagnetic sensors; worn bearings – using IR cameras; vehicles identifying – video cameras and so on. This paper discusses about a new concept of WIM sensor, designed in COMPETE project from “Gheorghe Asachi” Technical University of Iasi, developed for urban traffic monitoring, which can be integrated into Smart City structure and synchronise it with intelligent transport systems. This new concept can be useful for the local municipality, for traffic monitoring agencies and for avoid traffic gems.

Key words: WIM sensors, Safety, Traffic monitoring, WIM design.

Introduction

Weigh-in-motion (WIM) sensors were developed for determine the overload vehicles, protecting the road infrastructure and improve the road safety [1]. On European’s roads year by year the heavy-duty vehicles increase and the last report of European Automobile Manufacturers Association show that in European countries there are 6.3 million trucks [2]. The overloading trucks represents a danger for traffic safety and for lifespan of road infrastructures. The overload of the vehicles affects also the air pollutions and because the auto park increases, the greenhouse effect produced by vehicles creates a seriously risk for public health. Road transportation is responsibly by producing 17% of greenhouse gases. An overload of 10% determine a reduction of road infrastructure lifetime by 32%, which is equivalent of 5 years from a total of 16 years - as is the estimated average road life, in which there a normal wear is produced; after this period the normal degradation is very accelerated [3].

The pavement performance is characterized by level of traffic and types of vehicles which passed daily. The magnitude, loading configuration and number of loads applied by commercial vehicles influence the performance. In road transportation the overloading lorries is considered a problem with a significant importance, because the overloading affects traffic safety by unstable the trucks, increasing the braking distance and causing overheating of tires, brake system and suspension [4]. By measuring the time intervals at which the axles pass over the WIM sensor and the vehicle speed, can be determined the number of axles, type of them (single, tandem or tridem), the distance between them and thus the vehicles that crossed the sensor can be classified into categories. With the help of these sensors, the traffic can be monitored by volume and structure. The WIM sensors are mounted in grooves that cross the road, with the active part of the sensor at the same level with the road pavement. The output signal is transmitted through connecting cables to a computer with an acquisition board, which is mounted in...
a metal box installed outside the road [5]. The WIM sensors need to perform many other important functions like: estimation of the wheel load, axle load and total weight of the vehicle; estimation of vehicle’s speed; classification of vehicles by number of axles and by weight; providing real-time data for have a real-time traffic situation etc.

The intrusive WIM sensors have some disadvantage like: installing the sensor on the road can take about 48 hours (in this time the traffic is closed) which can conduct to traffic congestion and because of traffic jams the level of pollution increase; the maintenance interval time is quite short; the sensors need to be calibrated on each 1-2 years; the estimation cost of a WIM sensor is high – approximately 100 000 euro/sensor [3].

Commercial WIM sensors

The most known sensors which are can find on the market are: bending plate, load cell and piezo quartz [2]. WIM sensors measuring the dynamic forces applied by tire on the active part of the WIM sensor and estimate the static gross weight of the vehicle.

**Bending plate sensors** – consist of two plates made by steel for each wheel of the vehicle, mounted with two inductive loops. The inductive loops detect the axle of the vehicle and known the distance between the loops it can be determine the speed of vehicles. The bending plate sensor which had the strain gauges glued on the interior part of the bending plate can determine the weight of the vehicle by measuring the change in resistance of strain gauges when the vehicle pass over [6].

**Figure 1 – Bending plate WIM system**

**Load cell sensors** – consist into a steel box, embedded into concrete, with a rigid top plate on the same level with the road. The force applied by the wheel is transmitting to the top plate which have mounted a single load cell in the middle of the plate. The load cell sensor can determine the weight of the vehicle by measuring the change in strain gauges’ resistance of load cell sensor when the vehicle pass over. There is some advantage of using this type of WIM sensor: are robust, have high precision and the maintenance is easy to make, but the larger cross-section, hard installation and the high initial costs can be some disadvantage which can make you to try another solution. The accuracy for this kind of sensors is ±6% [2]. T Septiana and D Zan have tested a WIM system based on load cell (build by them) and the measurement errors of this kind of system are: 8.94% for determining the speed of vehicles, 14.64% for determining the distance of vehicle axle and 10.21% for determining the vehicle’s load [7].
Bending plate and load cell are wide sensors. These sensors have the width larger than the length of the tire footprint.

**Piezo quartz sensors** – consists of an extruded aluminium profile inside which is mounted the piezoelectric material (quartz). At the top of the sensor is an epoxy sand pad. The sensor is embedded in the road with the pad at same level with the road. The tire apply force on the pad and transmits the force to quartz crystals and then on the road, through the aluminium profile. The piezoelectric materials give an output signal proportional with the force applied on it them. The formula used by all the piezoelectric sensors is [5]:

\[
U = \frac{k \Delta P \cdot F \cdot l}{L}
\]

(1)

where,

- \(U\) – output signal
- \(k\) – sensibility factor
- \(\Delta P\) – pressure variation which is applied to the sensor
- \(L\) – the length of the sensor
- \(l\) – the length where the pressure is applied

\[
F = \frac{c}{c+m} \cdot e^{-\frac{t}{T}}
\]

(2)

where,

- \(c\) – capacity of the sensor
- \(c+m\) – capacity of the sensor with connectors
- \(T\) – temperature function
- \(t\) – load applied time

Other types of sensors are also known, which are being tested in the laboratory or mounted on the road [5], [8]:

- Fiber optic sensors;
- Piezoceramic sensors;
- Hydraulic sensors;
- Piezocables and so on.

Patented technical solutions for weigh-in-motion sensors are also known:

**Hydraulic sensor**- consists of a tank with elastic walls, full of fluid, partially embedded in the road. When the wheel of a vehicle passes through the sensor, the upper wall of the tank deforms and the pressure in the tank increases in proportional to the force applied. The pressure is monitored by strain gauges or pressure sensors [9].

WIM sensors consist of a **platform supported by dynamometers**, having various lever mechanisms for transmitting force, stabilizing the platform, mounted to increase accuracy [10], [11], [12].

**WIM sensors for low-speed vehicles** – consist in a rigid platform supported by force transducers that are mounted on the joints [13].

Sensor consist of a **rigid platform**, containing at least two dynamometers that measure forces in the vertical and horizontal directions and mechanisms for transmitting forces. By measuring the forces in two directions result an increase of accuracy sensors [14]. Sensor consist of a rigid platform supported by two dynamometers [15].

The piezo-quartz WIM sensor is a narrow sensor. The sensors in this category have the width smaller than the length of the tire footprint [16], [17]. The weight acting on the wheel is determined by integrating the sensor’s output signal.

The main disadvantages of the commercial WIM sensors are:

- Sufficiently precise and reliable sensors are expensive;
- Cheap sensors are not sufficiently precise and reliable;
- Mechanical stress can affect the WIM sensors which are embedded in the road and, usually, they had the active part of the sensor at the same level with the road;
• Installation is expensive, disrupts traffic for long periods of time and for this reason their relocation is difficult and expensive;
• Maintenance work for these sensors disrupts traffic for significant periods of time which can conduct to traffic gems;
• There are designed for interurban traffic and there are not used for urban traffic. For this reason, this WIM sensors cannot be efficiently integrated in intelligent systems, like monitoring or estimating pollutant emissions in cities;
• The sensors with a very small cross section (basis on fiber optics, piezocables and so on) are completely embedded in the asphalt, below the road level. For this reason, their calibration in the field is altered with the wear of the asphalt layer above. There are also known cases of their destruction, when the wear of the asphalt has reached till the sensors, which come into direct contact with the tires;

WIM system for urban traffic monitoring
„Gheorghe Asachi” Technical University of Iasi has obtained a national funding of 1 million euros for the project “TUASI - COMPETE. Institutional development of TUASI by increasing the visibility and performance of research”. It was a national competition in the field of "Energy, environment and climate change". Only five universities in Romania managed to make a project proposal in this field, the concept proposed by the Technical University was second after the evaluation. The general objective of the TUASI-COMPETE project is to supporting the development of research skills and high-performance teams by increase the capacity and institutional performance of research, development and innovation of the Technical University "Gheorghe Asachi" of Iasi [18].

TUASI – COMPETE start with a local contest where teams consist on young researchers applied with them ideas. From a total of 23 applications only 10 of them was selected for financing by this project, using the fallower criteria of selection: scientific relevance, project results, impact and dissemination of results, project implementation methodology, resources and budget. The project which developed this new concept of WIM sensor destinatint to urban traffic monitoring obtained 23.5 points from a total of 25 points, occupied the 3th place after the first two projects obtained 24/25 points [19].

The main objective of this idea of a new concept of WIM sensor destinatint to urban traffic monitoring is to monitoring the vehicles and classify them by structure and volume. This sensor needs to be cheap, to have good accuracy and the time for installing and maintenance to be smaller than to commercials WIM sensors.

The WIM sensor for weighing vehicles and monitoring the urban traffic removes the mentioned disadvantages of the Commercial WIM sensors by being mounted in a sealed housing, having the shape and dimensions of a speed bumper, which is mounted on the road same way as the existing speed bumpers, the housing consisting of a rigid base plate, which includes two piezocables (for determining the speed of vehicles and identifying the number of axles) and an elastic curved (cylindrical) cover at the top, which has strain gauges glued inside. The housing can include other types of sensors, to increase accuracy (thermocouple, accelerometer, magnetic sensor for monitoring vehicle axle and so on). The speed can also be determined and corelated with the speed determined from the piezocables by using off-road radar.

For design the sensor it was used the Catia V5 and Solidworks software, free edition dedicated for students. In figure 2 is presented the WIM sensor assembly, Figure 3 – exploded of WIM sensor and in Figure 4 is presented the bending cover of the dispositive.
Figure 2 – Assembly of the WIM sensor:
1 – inferior plate; 2 – superior plate; 3 – lateral covers.

Figure 3 – Components of the WIM sensor assembly:
1 – inferior plate; 2 – superior plate; 3 – lateral covers; 5 – piezocables; 6 – rubber protection

Figure 4 – Superior plate with strain gauges:
2 – superior plate; 4 – strain gauges;
The sensor has the following advantages:

- This concept allows weigh-in-motion the vehicles and monitoring the urban traffic (classified by volume and structure);
- It is accurate, simple and cheap;
- It is easy to install/uninstall (it is fixed with dowels in asphalt, same as the speed limiters) and the installation does not require the excavation of a groove to cross the road;
- Includes two piezocables for determining the speed of the vehicle passing through it and thus it is no longer necessary to include inductive loops in the asphalt;
- It is reliable (no moving parts);
- It can be integrated in complex systems, such as "smart transport", "smart city" as well as in networks for forecasting and monitoring polluting emissions in cities [20], [21].

**Conclusions**

The WIM technology will be an important system for all countries for controlling the illegal overloading and also this technology it will be use also for urban traffic. It will can be integrating into intelligent smart systems which makes part of the Smart Cities. The future WIM systems will be developed for avoid the traffic gems, or restrict the heavy trucks to circulate in the city, for reducing the urban pollution by fluidizing the traffic flows in the mains intersections in the big cities.

This new concept of WIM sensor is just a start in developing the WIM systems for urban traffic, the main objective of this sensor is to monitoring the traffic, weigh-in-motion the vehicles and providing real-time data traffic which is so important for a good traffic management in the cities.

The advantage of the new concept are: WIM sensor is easy to install/uninstall, cheap and easy to manufacture, can provide real-time data traffic, if is broken can be replace it easy, no need to stop the traffic (it can be install by block the traffic lane by lane), can be integrated in intelligent system traffic and corelate the data traffic information, don’t have moving parts, the data acquisitions can made wireless, and so on.

This new concept of WIM sensor could be useful for: Local Municipality- can improve the tooling system by applying per kilometre/charge or can use this new concept of sensor to avoid traffic gems and to avoid increasing the pollution providing by traffic vehicles in specific zones; Traffic monitoring agencies – they can had an all-time controlling over the fleets by providing real-time data information; Other transportation companies – providing traffic data information in real-time.

There is a demand for WIM sensors adapted to the urban traffic environment. The current speed limiters, installed in cities, could be replaced with some of the new concept WIM sensors. They will fulfil both the role of the old passive limiters and new functions (weighing in motion, traffic monitoring and so on) thanks to this new concept. The new speed limiters can be installed on the main arteries of the cities. In a medium-sized city, several hundred sensors could be installed in the first phase. If they are integrated into an intelligent transport system, the number could reach several thousand.

**References**

[1] J Gajda, R Sroka, T Zeglen and P Burnos 2013 The influence of temperature on errors of wim systems employing piezoelectric sensors *Metrology and Measurement Systems* Vol. XX, No. 2, pp. 171–182 DOI: 10.2478/mms-2013-0015

[2] I Agape, A I Dontu, A Maftei, L Gaiginschi and P D Barsanescu 2019 Actual types of sensors used for weighing in motion *IOP Conf. Ser.: Mater. Sci. Eng.* 572 012102 doi:10.1088/1757-899X/572/1/012102

[3] A I Dontu, L Gaiginschi and P D Barsanescu 2019 Reducing the urban pollution by integrating weigh-in-motion sensors into intelligent transportation systems. State of the art and future trends *IOP Conf. Ser.: Mater. Sci. Eng.* 591 012087 DOI: 10.1088/1757-899X/591/1/012087

[4] M Bosso, K L Vasconcelos, L L Ho and L L B Bernucci 2018 Use of regression trees to predict overweight trucks from historical weigh-in-motion data *Journal of Traffic and Transportation Engineering (English Edition)* https://doi.org/10.1016/j.jtte.2018.07.004
[5] P D Barsanescu, P Carlescu and A Stoian 2009 Senzori pentru cantarirea autovehiculelor in miscare Ed. Tehnopress, Iași ISBN 978-973-702-685-9
[6] L Zhang, C Haas and S L Tighe 2007 Evaluating Weigh-In-Motion Sensing Technology for Traffic Data Collection Annual Conference of the Transportation Association of Canada Saskatoon, Saskatchewan
[7] T Septiana and D Zaini 2018 Perancangan dan Implementasi Sistem Monitoring Beban dan Kecepatan Kendaraan Menggunakan Teknologi Weigh in Motion Journal Nasional Teknik Elektro Vol. 7 No. 1 p-ISSN: 2302-2949 e-ISSN: 2407-7267
[8] Y S Moon, W H Son and S Y Choi 2014 Characteristics of a Double-Tube Structure for the Hydraulic WIM Sensor Journal of Sensor Science and Technology Vol. 23, No. 1 19-23
[9] Patent US2017146384A1 – 2017 (S.U.A.): A Demozzi and M A Caponero Loading plate for weighing systems of vehicles in motion and related constraint system (Holder: IWIM SRL, Trento)
[10] Patent SU1465713 A1 -1989 (USSR): V Lynkov, D Kajdanov and S Chernousova Scales for weighing vehicles in motion
[11] Patent UA66460A -2003 (Ukraine): B G Yakovych Device for weighing vehicles in motion
[12] Patent UA67937A - 2003 (Ukraine): S V Ivanovych, L V Vasyliovych et al. Weigher for axis-by-axis weighing of vehicles in motion
[13] Patent US2017030764A1 - 2017 (S.U.A.): J Lawn, D Pearson et.al. Slow speed weigh-in-motion system with flexure (Holder: Rinstrum Pty. Ltd., Acacia Ridge Qld.)
[14] Patent WO2012010943A1-2012: M Trakhimovitch System and method for weighing vehicles in motion (Holder: Shekel Scales Ltd.)
[15] Patent WO2013139284A1 - 2013: Z Yingjie, L Yuan and Z Tao Device for weighing vehicles in motion (Holder: Pantian Technology Development Co.)
[16] Patent US2014309966A1- 2014 (S.U.A.): D Cornu and A Hofmann Method for weighing a vehicle, measuring system and measuring arrangement therefore (Holder: Kistler Holding AG, Winterthur-Elvetia)
[17] Patent US2015075297A1 – 2015 (S.U.A.): D Cornu and A Hofmann Hollow profile for a weight-in-motion sensor (Holder: Kistler Holding AG, Winterthur-Elvetia)
[18] https://www.tuiasi.ro/noutati/universitatea-tehnica-gheorghe-asachi-din-iasi-a-castigat-un-project-de-cercetare-de-1-milion-de-euro/ - accessed on 15.03.2020
[19] https://www.compete.tuiasi.ro/ - accessed on 16.03.2020
[20] H N Alwakiel 2011 Leveraging Weigh-In-Motion (WIM) Data to Estimate Link-Based Heavy-Vehicle Emissions MS thesis Portland State University
[21] T Haugen, J Levy, E Aakre and M E Tello 2016 Weigh-in-Motion equipment – experiences and challenges Transportation Research Procedia 14 1423 – 1432

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