In-Vehicle IoT Platform Enabling the Virtual Sensor Concept: A Pothole Detection Use-case for Cooperative Safety

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Keywords: Pothole Detection, IoT Platform, Virtual Sensor, Automotive, Intelligent Transportation System (ITS), Autonomous Vehicle, Smartphone, 6LoWPAN Sensor, Inertial Measurement Unit, Accelerometer.

Abstract: Nowadays the number of on-board sensors increases continuously due to their benefits in many different areas, such us driving efficiency, maintenance, autonomous driving, etc. Usually the vehicle itself and its users are those which take direct advantage from these benefits. By leveraging Internet-of-Things (IoT) technologies, it is possible to abstract data and functionalities provided by on-board sensors and actuators exposing relevant services outside the vehicle to external cloud-based applications and other vehicles. With these technologies the vehicle is thus transformed in an IoT object which can be part of external IoT platforms. This work focuses on the design and implementation of an in-vehicle IoT platform which exposes internal functionalities as IoT services enabling also the concept of "Virtual Sensor", which leverages sensor fusion techniques to provide enhanced services combining raw data coming from on-board devices. This IoT platform solution is validated through a use case in which virtual real-time pothole detection sensor is implemented to evaluate the road surface conditions. In such use-case, multi-source sensing information - coming from 6LoWPAN sensors as well as Smartphones and Inertial Measurement Units - is fused, enabling IoT applications such as cooperative safety and early road maintenance.

1 INTRODUCTION

Today's autonomous driving applications are relying on autonomous vehicle systems in which the needed information is gathered, processed and analysed on the vehicles themselves. Automated vehicles largely rely on on-board sensors (LiDAR, radar, cameras, sensors…) or interconnects surrounding sensors (cameras, traffic light radars, road sensors…) to detect the environment and make autonomous cars a full entity in the IoT eco-system. This paper is based on the use cases carried out during the European project AUTOPILOT (Ertico, 2017), that focuses on utilizing the IoT potential for automated driving and making data from autonomous cars available to the Internet-of-Things. In this way the Automated vehicle systems consist of inputs from a large variety of sensors, data signal condition and decision making by central or edge processing units and outputs to a large variety of actuators. The overall objective is to bring together relevant knowledge and technology from the automotive and the IoT value chains in order to develop IoT-architectures and platforms which will bring Automated Driving towards a new dimension. In order to demonstrate how additional IoT sensors placed in the AUTOPILOT prototype can enhance the functions of the car itself, the vehicle can be used for example as an IoT sensor for detecting the surface condition for both highway and urban scenarios.

Smart sensors and actuators in the vehicles, roads and traffic control infrastructures collect a variety of information to serve enhanced automated driving, while considering the timing, safety and security constraints (Maag et al., 2012).

Road surface anomalies, such as potholes, speed bumps, railroad crossing and joints, can determine some problems for vehicles and can affect road users safety. Road quality assessment plays a key role in infrastructure management and it is useful to an adequate allocation of road maintenance operations (Mukherjee and Majhi, 2016).

A pothole refers to a shallow pit on a road's surface, caused by activities like erosion, weather, traffic and some other factors. Detecting and hence avoiding potholes may reduce the fuel consumption, wear-tear and maintenance cost of a vehicle. With the availability of information regarding the road

Bosi, I., Ferrera, E., Brevi, D. and Pastrone, C.
In-Vehicle IoT Platform Enabling the Virtual Sensor Concept: A Pothole Detection Use-case for Cooperative Safety.
DOI: 10.5220/0007690602320240
In *Proceedings of the 4th International Conference on Internet of Things, Big Data and Security (IoTBDS 2019)*, pages 232-240
ISBN: 978-989-758-369-8

conditions, road users can be cautious about or avoid the bad spots (Langle and Dantu, 2009), in addition, Autonomous vehicles can make the right manoeuvres to avoid potholes or other dangerous situations. It is desirable to have a mechanism for detecting the condition of roads and get them repaired as soon as possible. As a result, working on monitoring road conditions has gained significant attention in recent time.

Related with the concept of Fog Computing, since there is no sensor on the vehicle that "physically" detects the roadway potholes, it is thought to use a combination of sensors that can already be integrated into the Original Equipment Manufacturer (OEM) dispositive (e.g. accelerometers, gyroscopes, etc.) or use sensors from external devices to be placed on-board (e.g. smartphones, cameras, external accelerometers, etc.) to recover the same type of data (acceleration, orientation, etc.) (De Silva et al., 2013).

This study proposes a pothole detection method based on the in-vehicle platform that will act as a “virtual sensor” for vibration. The information can be taken by 1) a 6LoWPAN sensor, 2) a smartphone/tablet or 3) an Inertial Measurement Unit (IMU). The “virtual sensor” can work with only one source of information or combines different sources. The accelerometer data is normalized and is adopted in the pothole detection algorithm to obtain the pothole information (interpolation with global positioning system (GPS) data). When a pothole is detected, a message is sent to the OneM2M cloud platform (Scarrone, 2016) where it is available for all the other vehicles and services. The proposed real-time pothole detection method based on mobile sensing includes three main steps: (1) accelerometer data normalization, (2) pothole detection algorithms, and (3) pothole location determination.

Till now, smartphones used for road condition monitoring, is limited to recording of accelerations, processing them to discern potholes and monitoring the overall condition of road surfaces. Therefore, the data must be pre-processed before it can be used. This can be done for example by using a passband filter. It removes low and high frequencies from the measured data. This makes the data much cleaner and easier to process. Data can also be divided into small segments and normalized to some specific scale to make the feature extraction and classification easier (Aksamit and Szmechta, 2011).

Our main goals are to classify road surfaces and further evaluate road conditions. Two basic categories for describing the road surface has been defined: smooth roads and rough roads (roads containing surface anomalies). A smooth road offers a high-quality driving surface to vehicles traversing over it, while a rough road is its complement.

The study begins with a general overview of the different already implemented methods for the detection of the road bumps, followed by the presentation of IoT platform on board vehicle implemented in AUTOPILOT project. Then the core of this work related to pothole detection is described and the developed algorithms with the procedures adopted in the tests are presented. Finally, the discussion of the first results obtained and the conclusions of the entire work are proposed.

2 STATE OF THE ART

With the increasing popularity of new road technologies and smartphones among people, researchers are showing interest in building smart IoT solutions using smartphones (because of the embedded sensors, like a GPS, accelerometer, gyroscope or magnetometer) or other image recognition methods in order to monitoring overall condition of road surfaces and improve the driving safety.

An image processing approach was proposed by Danti et al., (2012) where the potholes are first photographed or recorded using camera on a car. The algorithm that process these images of the road, represents the pothole as a distinct black colour.

Also Mertz (Mertz, 2011) uses light sensor and a camera mounted on vehicles (equipped with GPS) to detect road damages. The data is collected from many vehicles, aggregated and analysed at a central location and the assessment results are displayed interactively to facilitate road maintenance operations. A similar approach was provided by (Balakuntala and Venkatesh, 2013): the system comprises a laser sensor and pressure sensors in shock absorbers to detect and quantify the intensity of a pothole, a centralized server which maintains a database of locations of all the potholes which can be accessed by another unit inside the vehicle.

In a recent study (Jothi et al., 2010), the potholes and the hump locations are detected using GPS, GSM and Ultrasonic sensor, to alert the driver, reduce the vehicle speed decreasing the accident impact and consequently the vehicle damage. One database server collects the information about the potholes and humps and the information are sent to government authorities through the TCP protocol.

Regarding the use of smartphones, Wang et al., (2015) proposes a pothole detection method based on the mobile sensing (G-sensors and GPS) and shares the pothole information with road users and government. The accelerometer data is normalized by Euler angle computation and is adopted in the pothole detection algorithm to obtain the pothole information.

In a different study (Astarita et al., 2012), the accelerometer of five different devices (all placed in a test vehicle in three different placement conditions) is used for detecting surface conditions, using three different filters to analyse acceleration signals. Moreover, verification of the rate of false detections and undetected road anomalies is planned, using georeferenced photos that allow the correct localization on the map and the assessment of the correspondence between the elements, detected with the accelerometer, and real road conditions. Also Kalra et al., (2014) used data from smartphone accelerometer sensor: various thresholds are set and used for distinguishing and classifying various driving events and road anomalies.

The accelerometer sensor and navigation system interfaced microcontroller based embedded device mounted inside the vehicle works as a pothole inspector which updates the database on instant basis for every single experienced pothole (Aniket and Vivek, 2016).

A recent study (Akinwande et al., 2015) proposed a real-time pothole detection and traffic monitoring system and has been able to harness smartphone sensors to solve a global challenge, applying Machine Learning to a real world problem and developing a scalable and reliable system driven by the power of crowdsourcing.

Jakob Eriksson (Eriksson et al., 2008) have proposed The Pothole Patrol: this system uses the inherent mobility of the participating vehicles, opportunistically gathering data from vibration and GPS sensors (3-axis accelerometers and GPS sensors mounted on the dashboard of cars) and processing the data to assess road surface conditions. It not only identifies potholes but also differentiate potholes from other road anomalies.

Another method (Bhoraskar et al., 2012) uses Smartphone sensors for traffic state monitoring and detection of bumps. This system reorients the phone in two steps using accelerometer and magnetometer. The accelerometer sensor data is classified using k-means clustering algorithm into two classes which is labelled manually as either smooth or bumpy (for bump detection) and brake or not (for braking detection). This labelled data is used to train Support Vector Machine (SVM) for classification of data points during test phase for vehicle state prediction.

Also Bhatt et al., (2017) assess roads using gyroscope and accelerometer sensors in the phone, training SVM models to classify road conditions with 93% accuracy and potholes with 92%. Then, the classification results are used to create data-rich maps that illustrate road conditions across the city.

Nericell (Mohan et al., 2008) focuses specifically on an array of sensors; accelerometer, microphone, GSM radio, and/or GPS sensors are used to detect potholes, bumps, braking, and honking. They also proposed a method to virtually reorient a disoriented accelerometer and to use multiple sensors in tandem, with one triggering the other, to save energy.

Mednis et al., (2011) describes accelerometer data based on different Android smartphones, for pothole detection algorithms deployed on devices with limited hardware/software resources. They have proposed four algorithms for detection of potholes in real-time and for off-line post-processing of data.

3 IN-VEHICLE IOT PLATFORM

Thanks to AUTOPILOT's aim, the IoT eco-system will involve vehicles, road infrastructure and surrounding objects in the IoT, with a particular attention to safety critical aspects of automated driving.

Extending the work described in (Ferrera et al., 2017), the IoT in-vehicle platform of the AUTOPILOT's Italian Pilot Site is a modular software including Application Container and Communication System, which are deployed on the On Board Unit (OBU) inside the vehicle. The "Runtime Environment" part of the OBU is composed by several software modules, as showed in Figure 1.

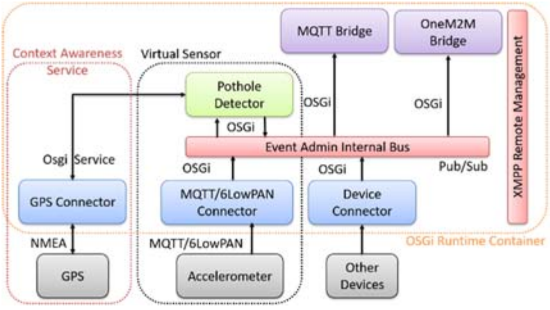


Figure 1: Italian IoT in vehicle platform AUTOPILOT project.

The functionality of Remote Management is implemented by a software (*OSGi remote management tool*) (Ferrera et al., 2017), that allows to configure the platform by adding/removing bundles, introducing the idea of remote monitoring and control of external application based on OSGi platform. Through the Event Admin Internal Bus the connectors have the same communication interface to the bundles which they interfaced in the Application Container.

The Application Container also encase the functionality of Data Management, with the modules implementing a Local Dynamic Maps (LDM) and the Pothole Detector. *LDM* is a database that achieves integrated management of static digital map information and dynamic object information such as the one coming from vehicles (functional requirement of Context Awareness). The bundle of *Pothole detector* represents the implementation of the pothole detection algorithm. It is based on data fusion techniques in order to implement the concept of "virtual sensors". This module collects data from multiple sensors on the vehicle (IoT in-vehicle components or OEM in-vehicle components), processes the various data and sends the results of this elaboration to the cloud OneM2M platform or Road Side Units or other vehicles (via communication system).

Regarding the IoT device adaptation, it is planned to support different IoT communication protocols with the devices: the IoT connector are used to integrate with 6LoWPAN data coming from additional IoT devices (i.e. Inertial sensors), that are used by edge applications on the OBU (*CoAP/6LoWPAN connector*) and also to integrate with MQTT protocol data coming from additional IoT devices (i.e. smartphone), that are used by edge applications on the OBU (*MQTT connector*).

The "Communication System" part of the OBU, manages different high-level capabilities. The module *CANBus Interface* reads data coming from the CAN Bus and decodes important data coming from the in-vehicle sensors that are sent directly to the OneM2M platform or used by edge applications on the OBU.

4 "VIRTUAL SENSORS"

The innovative and relevant part of this study is to demonstrate how additional IoT sensors placed in the car prototype, in conjunction with a centralized (OneM2M) platform for data collection, can enhance the functions of the car itself: the vehicle can be used for example as an IoT sensor for detecting the surface condition for both highway and urban scenarios.

Object virtualization aids to address the issues of heterogeneity, interoperability, multitenancy, scalability, counter-productivity, mobility and protocol inconsistency that are commonly existing in IoT. Related with the concept of Fog Computing, since there is no sensor on the vehicle that "physically" detects the roadway potholes, it is thought to use a combination of sensors that can already be integrated into the OEM dispositive (e.g. accelerometers, gyroscopes, etc.) or use sensors from external devices to be placed on-board (e.g. smartphones, cameras, external accelerometers, etc.) to recover the same type of data (acceleration, orientation, etc.).

This is the concept of "Virtual Sensor", that differentiates the study conducted by previous ones. In this way, data from different devices are fused together and processed: from this sensor fusion outputs, the data can be used to detect the road holes. The result of this fusion is therefore a "pothole detector" and these elaborations are sent to the cloud OneM2M platform or RSU or other vehicles (via communication system).

The data of the raw signal accelerations on the 3 axes will be collected and analysed using an inertial 6LoWPAN, a Nokia 6 smartphone and the accelerometer sensor of an inertial measurement unit (IMU). Figure 2 shows these devices.

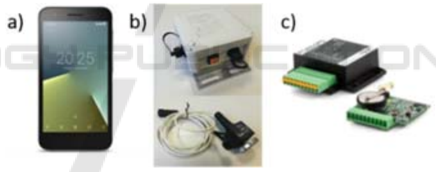


Figure 2: a) Nokia smartphone, b) 6LoWPAN Sensor, c) Inertial Measurement Unit.

The virtual sensor can use one or more acceleration sensors combining the upcoming data in a smart way (Figure 3). The accelerometer measures changes in velocity of the sensor in three dimensions: the linear sensing provides the sensor information about its motion and thus taps, or shakes can be detected.

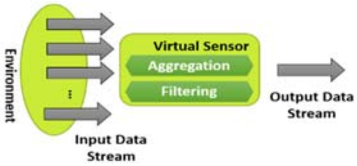


Figure 3: "Virtual Sensor" concept.

The flow of raw data is (Figure 4):

- A wireless vibration sensor is deployed on the connected vehicle, which notifies to the OBU via MQTT/6LowPAN protocols the occurrences of vibrational shock above a certain level due to a pothole presence on the road;
- The OBU combines this information with other data coming from CAN bus (speed, odometer, etc.) and GPS and sends this data to the OneM2M IoT Cloud platform, by using CoAP/MQTT and/or HTTP as application protocols;
- The AD car applications or upcoming AD vehicle, consumes the information and can arrange its speed accordingly (Crowdsourced data can be retrieved via a OneM2M subscription and used by other vehicles.)

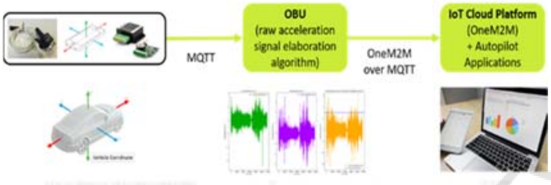


Figure 4: Pothole detector algorithm.

5 EXPERIMENTAL SETUP

Road anomalies, such as potholes, sunk-in manhole covers, or missing pavement, cause the abnormal vibration of vehicles.

The accelerometer records all vehicle vibrations including vibrations from the engine and the gear box and all swings made by passengers: the linear sensing in the direction of motion of the vehicle to identify the braking, and in the direction perpendicular to the direction of motion of the vehicle to identify bumps and potholes. Similarly, orientation can be determined by the sensor's sensitivity to the local gravitational field.

A continuous stream of data related to the linear acceleration of the vehicle on three principal axes, will provide additional measurements related to distance travelled by the autonomous vehicle, providing data related to the velocity and the extent of acceleration towards obstructions (Figure 5).

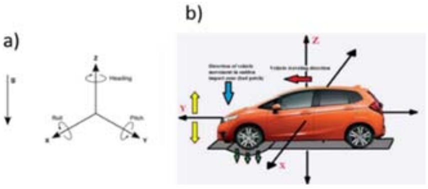


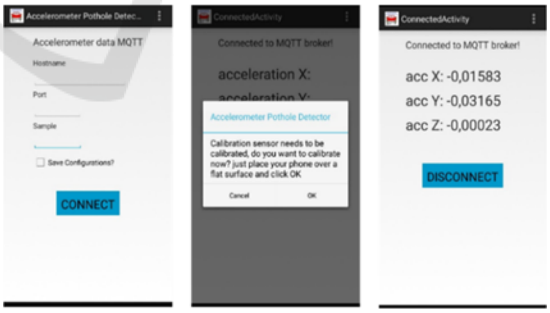
Figure 5: a) Gravity vector and heading, pitch and roll about axes b) Downward jerk sensed by accelerometer which occurred due to potholes over the road.

The data from the accelerometer is conventionally reported in units of g (1g= 9.81 m/s^2). In the initial condition and calibration, the accelerometer reports a value of 1g along the z-axis and 0 along the x and y axes when lying at rest face upon a flat table. The gravity vector thus reported is used as a reference for all other linear motion sensing. As already mentioned in this case of study, the data of the raw signal accelerations on the 3 axes will be collected and analysed using a Nokia 6 smartphone, an inertial 6LoWPAN sensor and the accelerometer sensor of an inertial measurement unit (IMU). The virtual sensor can use one or more acceleration sensors combining the upcoming data in a smart way. To better understand the different types of sensors used during the tests, will be made a summary regarding the characteristics of the devices used to collect the raw acceleration values.

5.1 Smartphone Accelerometer

To use the accelerometer reading for detecting various events, it is possible to virtually reorient the axes of the smartphone to align along the axes of the vehicle. Readings from the reoriented axes can be used to detect events. Leveraging an accelerometer as a vibration sensor, the characterization of potholes and roads can be done using the readings of the accelerometer.

It was implemented an App in Android Studio to collect the raw accelerometer data in the three directions and send the data to a MQTT broker (Figure 6).



Connected to MQTT broker!

Calibration sensor needs to be calibrated, do you want to calibrate now? just place your phone over a flat surface and click OK

Connected to MQTT broker!

acc X: -0,01583
acc Y: -0,03165
acc Z: -0,00023

Figure 6: Android App raw accelerometer.

The using of the mobile device based on mobile sensing techniques to detect potholes, is suitable and convenient: all the motion sensors return multi-dimensional arrays of sensor values for each *SensorEvent*. The linear acceleration sensor provides with a three-dimensional vector representing acceleration along each device axis, excluding gravity. [linear acceleration= acceleration -

acceleration due to gravity]. The simplest way to remove the offset of a linear acceleration sensor, is to build a calibration step into the application, in order to iterate the alignment of the smartphone accelerometer's coordinate system and the vehicle's coordinate system (Android, 2018); (Android, 2018).

Smartphone accelerometers use the standard sensor coordinate system. In practice, this means that the following conditions apply when a device is lying flat on a table in its natural orientation (see Figure 7):

- If the device is pushed on the left side (so it moves to the right), AccX value is positive.
- If the device is pushed on the bottom (it moves away from you), AccY value is positive.
- If the device is pushed toward the sky with an acceleration of A m/s^2, AccZ is equal to A+9.81, which corresponds to the acceleration of the device (+A m/s^2) minus the force of gravity (-9.81 m/s^2).
- The stationary device will have an acceleration value of +9.81, which corresponds to the acceleration of the device (0 m/s^2 minus the force of gravity, which is -9.81 m/s^2).

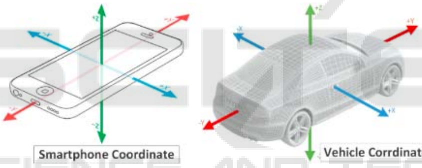


Figure 7: Coordinate system (relative to a device) that's used by the Sensor API.

5.2 6LoWPAN Sensor

The second sensor used to test the pothole detection setup, is an inertial unit that supply raw accelerometer data. SensOne leverages industry standard IEEE802.15.4 RF protocol for robust and power aware communication interfaces and USB2.0 connectivity (NGS, 2018). The SensOne has been designed for battery powered Internet of Things applications and natively supports state-of-the-art Internet addressing protocols (e.g. 6LoWPAN), to interoperate seamlessly with other devices.

The triple-axis MEMS accelerometer (12 bit-resolution) in MPU-6050 assembled in the SensOne, includes a wide range of features such as a programmable full-scale range (±2g, ±4g, ±8g and ±16g), orientation detection, signalling and tap detection. The values of accelerations sent are in thousandths of g (9.81/1000 m/s$^{\wedge 2}$).

5.3 Inertial Measurement Unit Accelerometer Sensor

The third type of sensor that can be used to acquire raw accelerometric data is the Inertial Measurement Unit (IMU) that is an electronic device that measures and reports a body's specific force, angular rate, and sometimes the magnetic field surrounding the body, using a combination of accelerometers and gyroscopes, sometimes also magnetometers.

A programmable sensor module ("PCAN-GPS") (Peak-system, 2018) for position and orientation determination, has a satellite receiver, a magnetic field sensor, an accelerometer, and a gyroscope. The sampled data can be transmitted on a CAN bus and logged on the internal memory card.

The BMC050 (Bosch, 2018) is a fully compensated electronic compass including a triaxial geomagnetic sensor and a triaxial acceleration sensor (6 degrees of freedom) that delivers excellent performance in very small size.

6 PROCESSING AND ALGORITHMS

The most common approach followed in previous studies for detecting road condition is using sensors to recognize the vibration patterns of the vehicle caused due to any deformity or obstacle on the road.

Our main goals are not only detecting single potholes, but also to classify road surfaces and further evaluate road condition, through the processing of the same raw data. There are two basic categories for describing the road surface: smooth roads (offers a high-quality driving surface to vehicles traversing over it) and rough roads (roads containing surface anomalies). The proposed real-time pothole detection method based on "virtual sensor" includes three main steps: accelerometer data acquisition and normalization, pothole detection approaches with algorithm of signal processing, and pothole location determination (GPS data). In Figure 8, the block diagram of the whole implemented algorithm is reported.

Different tests are performed in a test-drive track with an Autonomous Driving car and a smartphone blocked with a support horizontally on the windshield, in order to understand if the implemented algorithm offered good evaluation thresholds and analyse the first results obtained with the detection of potholes.

Figure 8: Block diagram real-time processing raw accelerometer "Virtual Sensor".

Data from the gravity and geomagnetic field sensors is used to transform the raw linear acceleration values from the device coordinate system into world's coordinate system: this transformation allows the device to be in any orientation while collecting data. In order to implement a real-time algorithm, it is important to integrate the raw accelerometer signals with the GPS data periodically acquired by a database: in this case it is possible to provide information about localization of the holes.

To collect raw accelerometer data from the different sensors, it is decided to use a frequency rate of 50Hz (repeatable frequency on all selected devices): supposing that the car have a travel speed of 50km/h (speed limit in an urban scenario), using this frequency rate, the road surface is monitored every 0.27 meters (compliant with potholes' dimensions). Unlike the technical tests carried out in other works on this subject, the 50Hz value chosen for the frequency is much higher and suitable for tests on urban circuits (and not just tests in lab).

The raw accelerometer data (whether coming from the smartphone, the 6LWPAN sensor or the IMU sensor) are input to a processing algorithm that uses a double comparison method to signal the single pothole (Figure 9).

The first and the simplest event is tested on the acquired data set (performed in a test-drive track with a car and a smartphone), divided into sampling windows, is thresholding the acceleration amplitude at Z-axis. The features that classify the measurements are the values exceeding specific thresholds that identify the type of the potholes, e.g. a large pothole or a cluster of potholes.

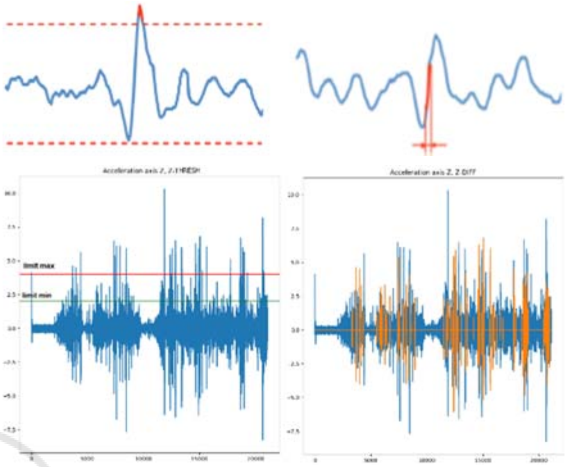


Figure 9: Threshold comparison method for raw accelerometer signals axis Z (Z-THRESH and Z-DIFF).

Next, a slightly more advanced algorithm is tested on the same acquired data set: it performs a search for two consecutive measurements with difference between the values above specific threshold level; thus the algorithm detected fast changes in vertical acceleration data.

The pothole will be indicated with the change in the value of z-axis: in this case an alert is sent to OneM2M Cloud every time a pothole or possible bump is detected. If there is no (or slight) deflection in the value of z-axis, then it is smooth road (no bump or pothole) and if there is any deflection, a bump or pothole is detected. If the magnitude of value of z-axis deflects firstly in positive direction and then towards negative direction with slight deflection, then it will indicate a pothole.

In order to classify the different thresholds for the bumps, it was evaluated all the different data training implemented and it is decided to have two different results:

- For 2≤|threshold|≤4 "possible pothole"
- For |threshold|≥ 4 "pothole detected"

The bump detection can be altered slightly to derive another concept for surface classification.

The main idea is to count the number of bumpy segments in a certain road section. Depending on that number, one of the classes "smooth", "rough", and "bumpy" is assigned as follows:

- For 0 ≤ |bumps| ≤ N/3 “smooth class”
- For N/3< |bumps|≤ 2N/3 “rough class”
- For 2N/3< |bumps| ≤ N “bumpy class”

The possibility of classify the types of road surface (from the optimal to the uneven), also occurs thanks to the additional values processed for the raw accelerations: it was decided to communicate every 30 seconds the values of minimum, maximum, average and variance of the 3 components acceleration (paying particular attention to the Z component) so that it is possible to process the data and compare it with the dangerousness of the road surface. All this processed data (related to single pothole and also concerning the classification of the types of road surface) are formatted using Data Model provided by Sensoris, that is actually coordinated by ERTICO (Here, 2018) (Sensor-is, 2018) and are send to the OneM2M Cloud to provide applications and services, or used by edge applications on the OBU (Figure 10).

Figure 10: Example of MQTT messages send to OneM2M Cloud.

As results of this quantitative tests performed in a test-drive track with an Autonomous Driving car and a smartphone, we create our model for the pothole detection algorithm both for the possibility of acquiring and processing the accelerometric data in real-time, both for using these prototype within a more complex and articulated IoT platform for the management of safety critical aspects of driving and maintenance of the road surface. For the 6LoWPAN sensor and the accelerometer sensor on the IMU, laboratory tests were carried out to set the detection threshold and to consider these solutions in an autonomous driving in an urban scenario (even if they are more expensive and less accessible than a common smartphone).

7 DISCUSSION & CONCLUSION

This paper explores the possibility of a real-time monitoring and processing for the automatic detection of pothole and humps, has a relevant role in order to reduce the vehicle speed, alerting vehicle drivers and then avoid potential accidents. The possibility to use different accelerometer sensors, not only related with AD cars (such as popular smartphone) is an additional advantage as it provides timely alerts about potholes and humps.

With the help of geographic information technologies (e.g. GPS), it is possible to establish new-strategy based solutions that use information about the condition of roadways. These solutions aim to help people and entities who are responsible for performing preventive as well as corrective maintenance to paved roads through continuous surveillance using their smartphones which are connected to a cartographic server that eases location and quality control of the work done.

A given pothole, or any other road anomaly, may not necessarily give the same pattern during each drive over it. The sensors readings depend upon the speed of the vehicle, how it approached the road anomaly and the position of the sensor (orientation). It also depends upon the suspension system of the vehicle (minimum/maximum vibration experienced by the vehicle).

Since this approach based on "bundles" for the architectural IoT system has been chosen, it is easy to select the accelerometric data collection system between smartphone, 6LoWPAN sensor and IMU: all the raw accelerometer data can be collected at a sampling rate of 50Hz and in the first tests that were carried out there were no gaps of accelerometric values obtained preferring one type of sensor compared to others.The proposed solution proven to be able to quantitatively evaluate the quality of the road: not only single potholes are detected but also longer stretches of low-quality pavement. This could allow taking the pavement quality into consideration while calculating routes for navigation system.

In order to improve the efficiency and accuracy of the detection of potholes and to enhance all this case studies, as future work, it has been planned to continue to perform more and different tests using AD cars (also in the AUTOPILOT scenario): with a larger test database, it will therefore be possible to exhaustively process the results obtained with the different sensors and to establish the reliability and the trust of the implemented algorithms.

This system could be also deployed with a neural network to implement Machine Learning on

Android: Machine Learning techniques can be applied instead of threshold-based classification as different vehicles may yield different sensor data for same pothole. It will make the system more efficient and introduce self-calibration functionality.

ACKNOWLEDGEMENTS

This work was supported by the European Union through the AUTOPILOT project (H2020-IOT-2016, grant agreement no. 731993).

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