2016 IEEE/ACM 20th International Symposium on Distributed Simulation and Real Time Applications

A Low-cost IoT Application for the Urban Traffic of Vehicles, based on Wireless Sensors using GSM Technology

Hugo Nugra, Alejandra Abad, Walter Fuertes, Fernando Galárraga, Hernán Aules, César Villacís, and Theofilos Toulkeridis

Computer Sciences Department, Universidad de las Fuerzas Armadas ESPE, Sangolquí, Ecuador

e-mail: {henugra, maabad2, wmfuertes, jfgalarraga, hmaules, cjvillacis, ttoulkeridis}@espe.edu.ec

***Abstract*—Congestion of vehicular traffic in the cities with the highest population density results into a high amount of accidents and also to imminent road violence above average. Facing this problem, our study intends to implement a low-cost Internet of Thing proposal, in order to monitor and analyze traffic circulation and provide solutions to reduce the above mentioned negative effects. To fulfill such proposal, a system of low-cost wireless monitoring has been designed and developed, which is supported on a distributed multilayer model. This system interacts with a device consisting of two electronic Arduino platforms, which themselves interact in master-slave mode having a distance sensor based on laser for detection of vehicles. The latter has the ability to connect to the Internet transmitting in real-time data taken by HTTP requests over the cellular network. On the data collected an engine for data mining is mounted in order to receive information about the traffic on highways and subsequently proposing potential solutions. The proof of concept has been applied in the city of Quito. There, on over their two central lanes of the Simon Bolivar Avenue such kind of solutions have been applied with positive results, both in the operation of the software and hardware that compose the prototype, as well as in reference measurements of traffic. Based on our findings, the system manages to suggest extrapolations, which enables to reduce traffic congestion, fuel waste, and also air pollution.**

Keywords—Congestion of vehicular traffic; Wireless Sensors; Arduino platform; celular network; data mining;IoT, monitoring

I. INTRODUCTION

Urban traffic congestion is a burning issue in many cities due to an exponential growth of vehicles in use [1], producing increases in travelling and bottleneck times. This phenomenon occurs commonly during peak hours, frustrating drivers, since time gets lost; fuel consumption, while accidents and vial violence increase. Based on these facts, the industry has focused its efforts in finding a versatile technological alternative that allows improving the traffic measurement process. Unfortunately, existing products and the results that have been generated did not provide low-cost solutions.

According to this scenario, the scientific community developed several studies concerning to traffic congestion using electronic devices with Arduino platforms. Therefore, our study has been structured by: (1) the type of collection of data; (2) its application; (3) its topology; and (4) its method of analysis. In relation to the type of collection of data, there are two subdomains: Eulerian and Lagrangian [2]. In regards to Eulerian studies [3][4] uses the method of analysis of images captured by cameras, [5][6] uses magnetic sensors to collect data, [7][8] applied the inductive method, [9][10] are based on Bluetooth sensors that pick up signals from devices that emit these waves, [11] use different type proximity sensors, [12] uses infrared sensors, [9] includes a combination of ultrasonic sensors, Bluetooth and laser. As an alternative, there is a Lagrangian type proposal, which uses moving devices such as cell phones. As instance, [3][13][14] capture data across nodes located in the vehicles, while [2][15][16] use mobile phones to read the traffic. Furthermore, there are studies [2][17] that merged both Eulerian and Lagrangian subdomains, using wireless sensors networks (WSN) and GPS cell phones.

Regarding to the application developed, [3] [11] [16] [18] [19] presents an application to observe the flow in real time, [2][8][9][19] focuses on finding traffic trends, [4][13][18] enhance simulation of traffic, [15][16][20] focuses on making a description of the traffic. With regard to the use of a network topology [10][12][13][21] centralized signals from nodes in one central to incorporating ZigBee devices. Finally, in reference to the method of analysis of the data collected, [22] uses a mathematical model, [18] incorporates software agents, and finally [9][16] apply origin - destination matrixes. In [23], the author explains how to reduce and eliminate hazards in traffic simulation with a new method optimizing computational resources. Despite all mentioned, any of these studies lacks in its research on data capturing the process on real time from the actual environment, and even more they are deficient in applying new data of mining techniques and live data presentations.

Faced this issues, the main objective of this work focuses on how to implement a low-cost Internet of Things

1550-6525/16 $31.00 © 2016 IEEE
DOI 10.1109/DS-RT.2016.24

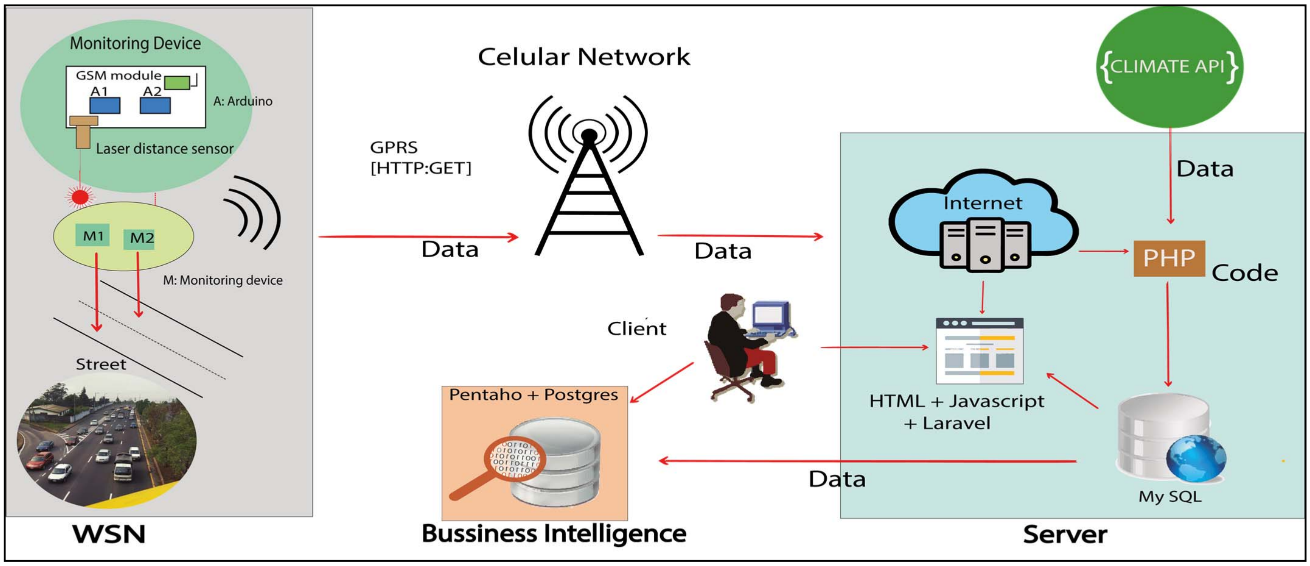

Fig. 1. An overview of the main components of this research as Wireless Sensor, Data mining / Bussines Intelligence, and Web Application development process. The Experimental Setup Section has divided into six sub sections such as: A. Traffic measurement device; B. Functional Software Requirements ; C. Software Architecture; D. Data mining / Business Intelligence; E. End-Product; and F. Funcionality Test.

(IoT) application [24], in order to monitor and analyze traffic circulation and provide solutions to reduce their negative associated effects. Therefore, we designed and developed a system of low-cost wireless monitoring, supported on a distributed multilayer model. This system interacts with a device consisting of two electronic Arduino platforms, master-slave, which has a distance sensor based on laser for detection of vehicles. This in turn, has the ability to connect to the Internet to transmit real-time data taken by HTTP requests over the cellular network. On the data collected we mounted an engine for data mining in order to get information about traffic on highways and then propose solutions.

Among the central contributions of this study includes: (1) using highly reliable data through checkpoints in the Avenue of Simon Bolivar in Quito, we have monitoring in real time of the state of the traffic; (2) accessing the traffic monitoring by means of a Web application, that helps users in decision-making regarding the traffic congestion of the city.

As mentioned, this system has been applied in the city of Quito, with stationing sensors on a strategic site being the bridge of the Inter-oceanic Avenue. We found the functionality of the prototype performing simultaneous counting of the left lane of both directions being North-South and South-North. The results were transmitted in real time via GSM module to a database in the cloud. The results based on these data, which have been generated by using this method, may also be applied worldwide in order to control better, more fluently, and efficient traffic having a proposed variety for new road alternatives to be followed.

The remainder of this paper has been structured in the following way: Section 2 describes the Experimental Setup, while the evaluation results are provided in Section 3. Section 4 finalizes the study with conclusions and future work lines.

II. Experimental Setup

This section presents and explains the design of the present study, which comprises the architecture of the electronic device and its characteristics, the development process and its architecture as well as functionality tests. This research has leveraged on a conceptual framework represented in Fig. 1 and is briefly described further below.

A. Traffic measurement device

The developed device has been mounted on two Arduino UNO R3 boards, which interact with each other in a master-slave mode, and each with a specific function. The first electronic board has the distance sensor based on laser Lidar Lite 2. This is controlled through the library offered by the developer, and along with an unpublished algorithm created in our project for the detection of vehicles, which is in charge of the traffic count. The second electronic board has the expansion module GSM, which requests the amount of cars that were detected by the first Arduino platform through the I2C Protocol during a configured time (i.e. the last five minutes, in this case). Subsequently, it sends this measurement along with descriptive information from the station through the network GSM/GPRS to the Web server.

In the present experiment, the ZigBee standard, being a wireless communication without Internet connection, has not been used. We applied such standard in a previous study [25], therefore it has been necessary to pertain the expansion module GSM that allows links to the Web server.

Concerning to the power supply that supplies electricity, a battery of 20000 mA has been used, distributed through two USB ports that remain lit to incorporated two Arduino platforms for a long time (see Fig. 2).

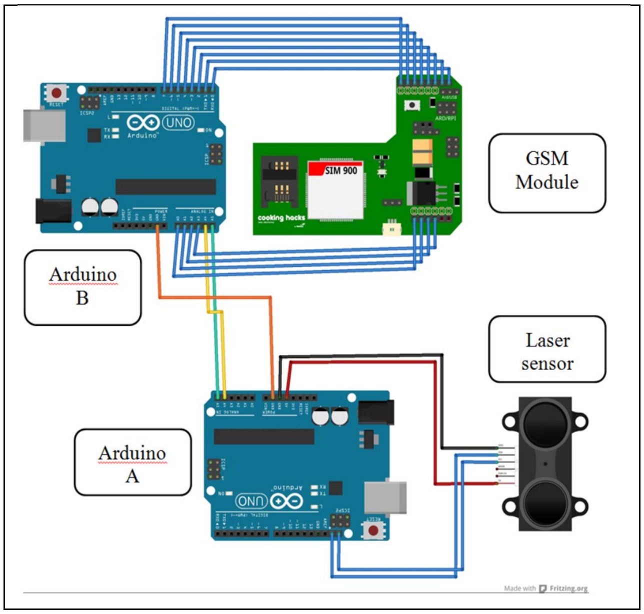

Fig. 2. Electronic scheme of the device of monitoring.

As illustrated in Fig. 2, all parts are assembled in the electronic device. The first Arduino platform has a GSM expansion module and works with a SIM 900 chip. This chip having the GSM technology allows the GSM/GPRS to connect to the signal provider. Simultaneously, the second Arduino platform has the distance sensor laser that uses the SDA and SCL pins. Both boards communicate via I2C port serial, requiring to its use to be interconnected with the analog pins A4 and A5, as well as with grounding pin.

This proposal is consistently framed within the concept of IoT. According to Doukas [24], IoT is a global network that links physical objects using Web applications and network communications. It allows devices to communicate with each other, it also lets to access information on the Internet, it enables to store and retrieve data and it interacts with users creating smart, pervasive and always-connected environments. There are already a few open platforms available that enable remote and seamless management and visualization of sensor data which with Arduino works properly.

To describe the behavior of the electronic device, Fig. 3 discloses how the parts that conform the device interact with each other in the following phases: (1) start of the application; (2) instantiation of variables and objects required; (3) connection to the cellular network; (4) application of the Arduino platform A distance to the laser sensor; (5) sending a request of the distance from the Arduino platform A to the sensor; (6) interpretation of the result to determine if a vehicle has passed and add it to a count variable; (7) when an interval of five minutes has been completed, Arduino platform B request to the Arduino platform A, storing the number of vehicles; (8) transmission of the number of vehicles to Arduino platform A; (9) establishment of the HTTP request to the server with the necessary data; (10) individual transmission of the HTTP request to the web server.

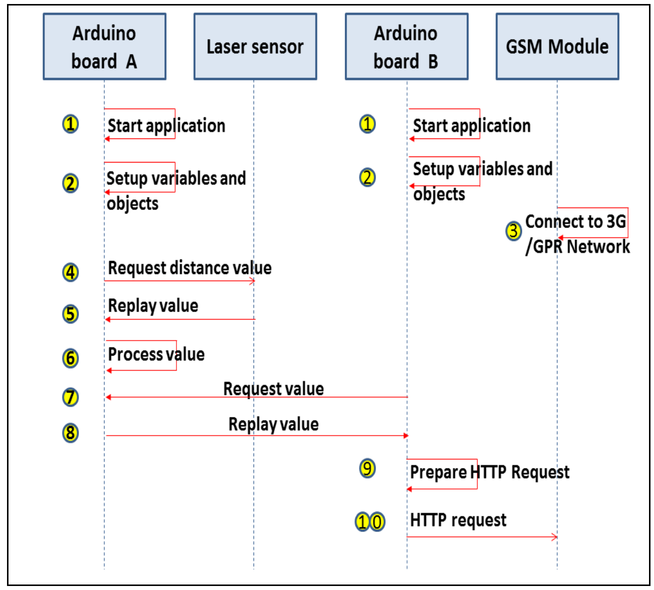

Fig. 3. Sequence diagram of the steps executed by the device of monitoring.

B. Functional Software Requirements

During the design of the monitoring system three main actors were identified who interact with the Web application and the electronic device responsible for the count of the vehicles. The first element must be the Web application, which records in the database the count of vehicles, and additionally check the climate by means of the API linked from openweathermap.org. The second element should be the Web application that allows the user to observe in real time the state of the traffic. The third required element must be able to apply data mining and obtain the analysis of the data collected through the Pentaho tool [26], which is used to feed a Business Intelligence solution.

To specify the communication and behavior of the monitoring device, through its interaction with users and other components, Fig. 4 illustrates the applied cases that were determined in the analysis of the project. These interacted in the following form: vehicle count is obtained from Arduino platform A, which firstly interprets the distance from the laser sensor using the algorithm developed on itself, and then secondly measures the number of vehicles travelling through the monitored pathway. Arduino platform B requests to Arduino platform A the vehicles count, sending every five minutes this information via the GSM/GPRS network. The device of monitoring is connected with the Web application to register the count and the climate in the database. This in turn is consulted by the system of monitoring that allows the user to obtain the statistics in real time. The use of Pentaho to the analysis of the collected data, becomes a useful tool in the decision making process.

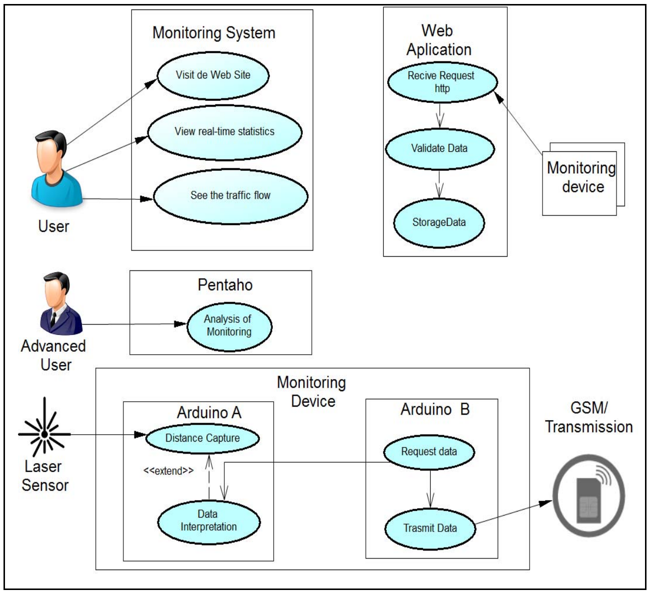

Fig. 4. Use cases identified in the analysis of requirements.

C. Software Architecture

According to Vyatkin Valery [27], the software architecture would drastically simplify industrial application of those advanced software concepts. In addition Pressman in [28] defends that the software architecture is a representation that allows analyzing the effectiveness of the design in order to meet the identified requirements, perform changes, reducing the risks at the time of programming the software. Within this context, Fig. 5 illustrates the architecture of our present research, which has been divided into three subsystems, having specific functions and interacting with the database. The first subsystem monitors that what has been developed in PHP and uses the Laravel Framework that implements three-tier architecture. The second subsystem is a Web application receiving data, which is developed in PHP and communicates by means of the HTTP protocol. The last system is a data mining process, which improves system performance monitoring by means of Pentaho. Pentaho prepares data integration, and blends data to create a complete picture of this issue that drives actionable insights. This platform delivers accurate, analytics-ready data to users from a monitoring device source [26].

The Model layer has been structured for the information generated by the device of monitoring (Fig. 5), taking into account the number of identification by station, generated count value, the date, and time of registration, as well as the climate at the time of data collection. This information will be consulted by the final users to obtain the traffic status in real time. Due to the direct interaction with the monitoring device the system requires only a single table named count. Instead, for the implementation of data mining, there has been the need of a multidimensional database, so that the star scheme has been able to be used to represent the behavior collected.

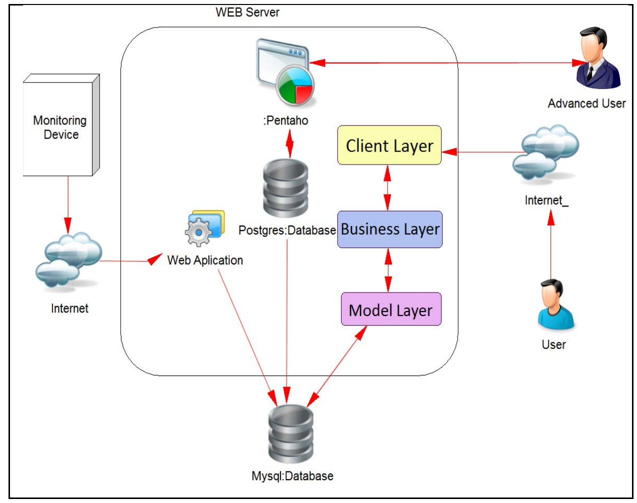

Fig. 5. The software architecture.

In order to achieve the interaction of the monitoring devices and the database, we have created a Web application, which enables the reception, processing, and storage of the information generated by electronic sensors. This subsystem developed in PHP operates independently within the architecture defined previously. Once the device of monitoring sends the information via the HTTP protocol, the Business Layer was used to obtain the API of the climate data. Then, through a connection the database records such information. At the same time, the Arduino platform creates a request type GET, by concatenating variables obtained by sensors within the URL sending them through the GSM module using the HTTP protocol. This information needs to be programmed on the Arduino platform B (see Figures 2 and 5). The data that are sent from the laser sensor to Arduino platform A, are analogue signals, which interpret the language of the Arduino programming in the same electronic board. This uses the sensor that allows obtaining the data of the distance in centimeters.

D. Data mining and Business Intelligence

In order to extract even more detailed information about the behavior of the traffic at the study site, incorporating new opportunities of business lines or other alternative solutions to the problem of vehicular traffic, the technological module Bussines Intelligent platform of Pentaho has been applied (i.e. BI server) that allows to work with cubes and multidimensional databases. This latter includes a variety of analytics tools from basic reports to predictive modeling, where users are able to help themselves to analyze and visualize data across multiple measures and dimensions.

Figure 6 indicates the Star model of the multidimensional database used. This model is a requirement for the formation of cubes that are a type of diagrams for the database. All data collected during the two-week period of our study were recorded in the Mysql DBMS. Afterwards, these data were copied and transformed to the multidimensional Postgres DBMS. Once completed, this requirement formed the OLAP cube from pentaho BI server, having access to the advantages of data mining.

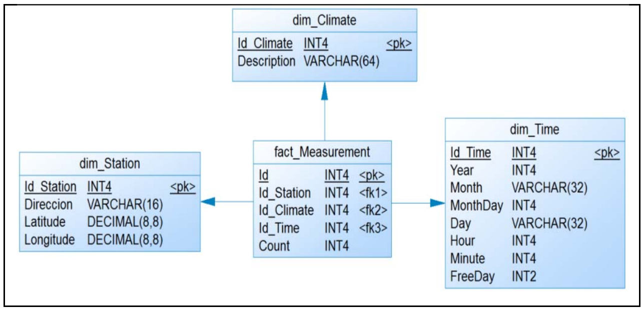

Fig. 6. Star schema to represent the behavior collected by sensors.

E. *Funcionality Tests*

These tests revealed that the functions of the software are operating, the inputs were accepted in the appropriate menner and that there has been a correct output, while the external information integrity has been maintained. Particularly, two agile methodologies as Scrum and Xtreme Programming (XP) were combined. They provided the necessary elements to cover all phases of the construction of software and hardware [29]. Scrum is responsible to the planning, implementation and documentation of the project, while XP focuses on the coding of software for the experiment.

For this study, it has been estimated a development duration of about four months, divided into three iterations or sprints. The methods used were: (1) Test-driven development (TDD), which is a method of software development in which unit testing is repeatedly performed on source code; (2) the incremental design which split a main problem into smaller problems; and (3) the continuous integration, which main aim has been to prevent integration problems. In this last phase, several units for each of the iteration tests were carried out using Scrum. In addition, the PHP-Unit tool of Laravel Framework has been used to generate necessary testing. The intention of testing has been to evaluate the behavior of the layers: client, business and data. The receiving data Web application has been tested with HTTP queries on Web browsers.

The proof of concept has been applied in the city of Quito, over the two central pathways of the Simon Bolivar Avenue with positive results, both in the operation of the software and hardware that compose the prototype as well as reference measurement of traffic. Based on our results, the system manages to propose alternatives which certainly enable to reduce traffic congestion, fuel waste, and also air pollution.

F. *End-Product*

The elements presented below are a fundamental part of the project. Fig. 7 shows the two devices used in the monitoring system with their internal electronics. Fig. 8 demonstrates the Graphical User Interface (GUI) of the Web application developed for the real-time traffic monitoring.

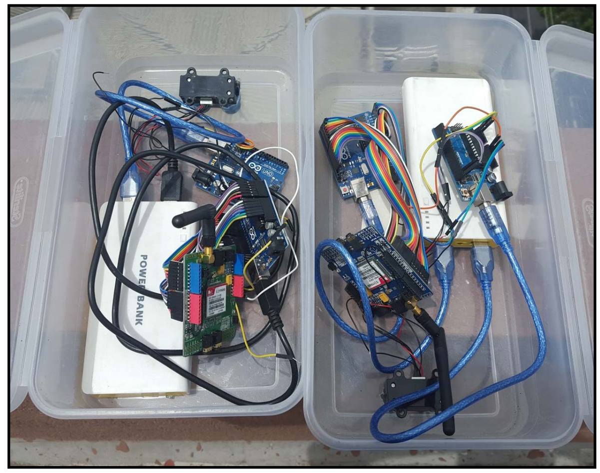

Fig. 7. IoT wireless electronic devise for traffic monitoring.

Fig. 8. Graphical User Interface which show real time data.

III. EVALUATION RESULTS

As previously explained in subsection II-F below "Functionality Tests", for the evaluation of the obtained results, direct observation (i.e. field research) have been performed at two fixed points of the Simón Bolívar Avenue of the city of Quito, using our devices for monitoring during four weeks in March 2016, recording in the database a significant amount of data. Obviously through the support of the Pentaho Tool, they were subjected to the following statistical analysis:

A. *Results obtained by Data mining*

After completion the process of collecting data, we decided that the most efficient way to use the amount of stored data may be the application of data mining. The chosen tool has been Pentaho with its element BI server in conjunction with the Saiku Analytics plugin. This is explained, due to the quality of the information, which has been described to the users through statistical graphs, demonstrating the behavior of the studied phenomenon.

Some of the most fundamental outcomes of interest have been, that in the South-North direction has been a greater vehicle flow having a total of 47.032, while the North-South rail has been of about 38.120 (see Fig. 9). Similarly, Fig. 10 demonstrates Wednesday to be the day in which most vehicles are passing with an 18.9% of the total amount of vehicles during the week, while the lowest frequented day has been Sunday with an amount as low as 7.9%.

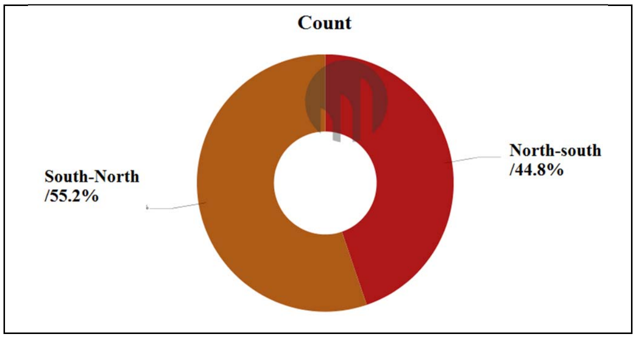

Fig. 9. Percentage of flow by lanes. Results exported with Pentaho.

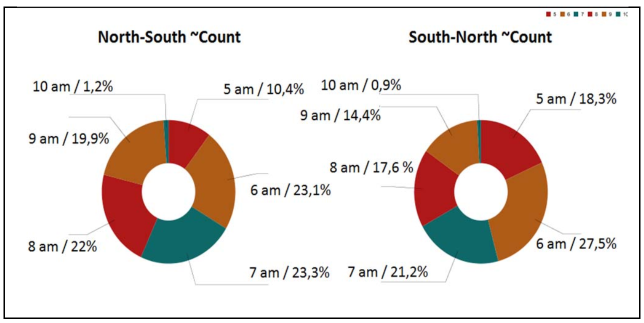

Fig. 10. Hourly flow illustred per hours/ lanes. Results exported with Pentaho.

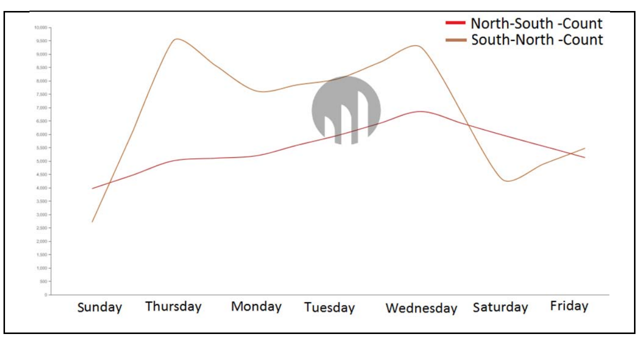

Fig. 11. Linear dispersion per day and per road. Results exported with Pentaho.

Fig. 11 illustrates the linear dispersion per day and per road, where it appears that Thursday and Wednesday are the days with most traffic, while Sunday is the day with minor congestion compared with all other days of the week. Only with this noted and determined behavior, the assigned authorities may take corresponding actions in order to avoid bottlenecks in the days of major traffic congestion.

Finally, Fig. 12 illustrates the hourly flow recorded in lanes with the influence a variety of different weather conditions. Clearly, in moderate rains the average value of hourly flows is the highest recorded followed by the values of weak rain, cloudless sky, few clouds, ending with scattered clouds.

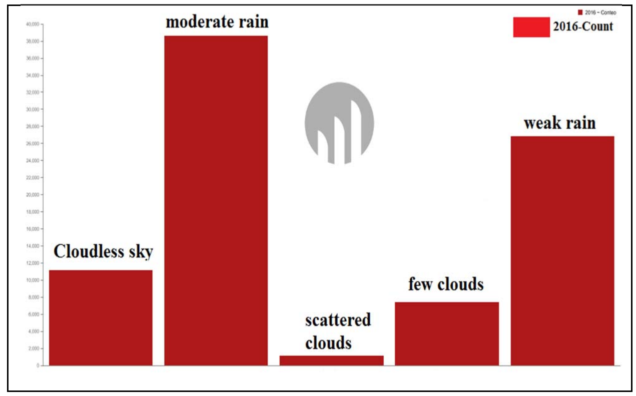

Fig. 12. Hourly flow recorded in lanes with different weather conditions. Results exported with Pentaho.

This type of information together with the corresponding roads is certainly a fundamental and useful for authorities responsible for the administration of the city traffic. Thus, with real time data they may be able to decide more efficiently which day and at what time requires a more detailed monitoring or control. Similarly it may pose solutions as counter flow roads in an avenue given the inequality of flow between the two senses.

B. Statistical validation

For this purpose, a statistical approximation has been used to the number of vehicles that pass by the Simon Bolivar Avenue in the city of Quito. Hereby, we have used the Poisson distribution, which is applicable to random events that occur over time. Likewise, we applied the Exponential distribution that models the elapsed time between two consecutive events modeled by the Poisson distribution, and determined its Probability and Density functions. Therefore, first we find the lambda parameter through the mathematical expectation as follows:

For the Poisson distribution is: $E[x] = \lambda$,

Where λ is the appearance average of the event in 'n' experimental tests.

For the exponential distribution is $E[x] = 1/\lambda$

Here it is necessary to determine the mathematical expectation of the random variable "x = count", which is a unique real number, thus:

$$E[x] = \sum_{k=1}^{n} p_k x_k$$

Where the $\mathbf{p_k}$ represents the relative frequencies of the random variable defined as "count". While the $\mathbf{x_k}$ represents the absolute frequencies of the mentioned variable.

The calculation of the mathematical expectation has been obtained for $\lambda = 15.55733$. The R language has been used in this calculation. Then the mathematical models for the mentioned distributions have been applied. In the Poisson distribution $x \sim P(\lambda)$ should be:

$$P_r[x = k] = \frac{e^{-\lambda}.\lambda^k}{k!}; k = 0,1,2, \ldots$$

And its mathematical expectation is $E[x] = \lambda$; therefore, and as noted, the experimentation has been collected in five minutes intervals, thus:

$$P_r[x = 5] = \frac{e^{-5}.15.55733^5}{5!} = 0.00133055;$$

$$P_r[x = 10] = \frac{e^{-10}.15.55733^{10}}{10!} = 0.04009819;$$

$$P_r[x = 15] = \frac{e^{-15}.15.55733^{15}}{15!} = 0.101406, \text{ and so on.}$$

These interpolations were used to perform various mathematical predictions of experimental behavior pointed out, as depicted in Fig 13.

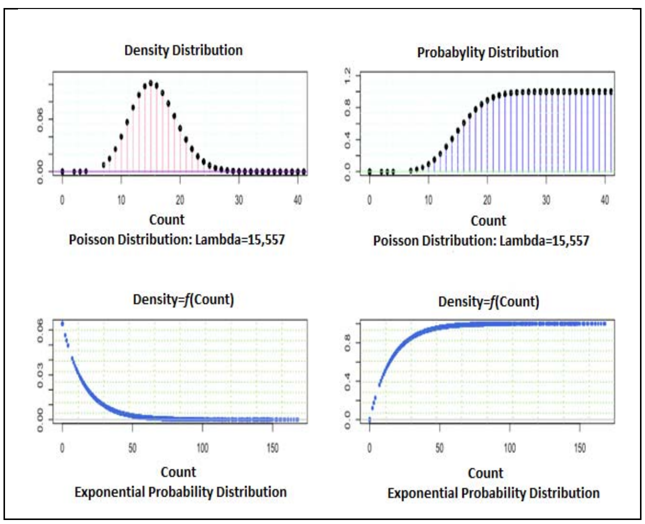

Fig. 13. Density distributions, Poisson and exponential probability.

Nonetheless, in relation to the variability of weather, we have considered the Exponential Distribution $x \sim E(\lambda_1)$ by the variability of time conditions (i.e., weather). Therefore, it's changing model of cloudless sky to weak rain, moderate rain, many scattered clouds, and few clouds, in its various changes of temperature.

The density function is:

$$f(x; \lambda_1) = \lambda_1 e^{-\lambda_1 x} \text{ for } x \geq 0; \lambda_1 > 0$$

Then, in the next Mathematical expectation:

$$E[x] = \frac{1}{\lambda}$$

We used the values of 5, 10, 15 and 20 minutes; which have a probability calculated as we can see in the Table I.

TABLE I. DENSITY FUNCTION VALUES

x (minutes)	f(x; λ1)	$\lambda_1 e^{-\lambda_1 x}$	Probability
5	$f(5; 0.06427838)$	$0.06427838e^{-0.06427838*5}$	4.66 %
10	$f(10; 0.06427838)$	$0.06427838e^{-0.06427838*10}$	3.37%
15	$f(15; 0.06427838)$	$0.06427838e^{-0.06427838*15}$	2.45%
20	$f(20; 0.06427838)$	$0.06427838e^{-0.06427838*20}$	1.77%

These obtained values, as well as the Poisson distribution calculated in the preceding paragraphs, allow us to infer the behavior of the traffic flow in the aforementioned motorways. Consequently, the assigned authorities may use these mathematical models to infer and even extrapolate the amount of vehicles that most probably use the highway in certain times.

Thus, calculation of our proposed model with the intervals of 5, 10, 15, and 20 minutes, generated probabilities of 4.66%, 3.37%, 2.45% and 1.77% respectively. Hence, probability of the Poisson distribution and its complementary models of Exponential Probability distribution are fundamental models to be able to predict the behavior of the vehicular flow in certain places where there is such kind of physical phenomena.

Based on these arguments, we have used box diagrams, considering the count of vehicles depending on the climatic conditions in different days (see Fig. 14). There, it is demonstrated that in moderate rains the average value is the highest of all determined ones, followed by the values of the parameters of a few clouds, weak and such rain between the cloudless sky ending with the lowest valued given by scattered clouds. Subsequently, this evaluation and consequence appears to be objective in view of the fact that these results are consistent with those obtained using data mining in Fig. 12.

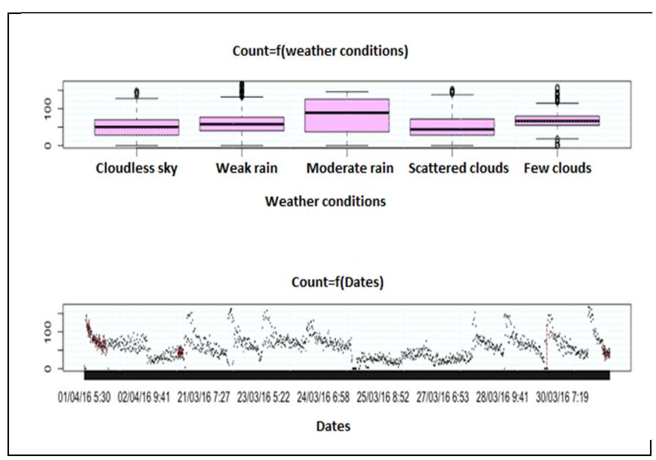

Fig. 14. Box diagrams by counting according to weather conditions.

Subsequently, this allows us to define that climatic conditions infer in certain seasons under conditions of moderate rains, which do not decrease traffic on specified highways. Based on traffic count, the highest peaks of the vehicular circulation occurred in March 2016 in the time period between 7:22 AM until 12:07 PM.

Furthermore, by means of the probabilistic and experimental analysis description using Poisson and Exponential distributions we were be able to define the different characteristics of traffic behavior describing the amount of the flow and the form of vehicles on any highway, being even able to predict them including hereby also the weather conditions.

C. Discussion

Some of the most obvious benefits and strengths of this study have been the use of the IoT Application for the Vehicular Urban Traffic system allowing monitoring traffic in normal conditions, congestion traffic, and even depending on the weather conditions. Such results may be used by researchers, teachers, and students, including authorities of the traffic Division in order to be able to use alternative solutions that improve the viability of this pathway or any road. During the development of this research we have combined agile methodologies to develop the GUI, with electronic Arduino platforms, the concept of data mining /BI, the cellular network, and the algorithmic programming.

This system appears to be a highly constructive resource for persons who are responsible in the monitoring of the traffic, in order to propose strategies to redistribute the vehicular circulation. Similarly, given that this system is relatively inexpensive ($200 per device), it may be frequently used at roads that have higher traffic density.

From the pure research point of view, this system allowed quantitatively to evaluate a classic problem of cities with a classically high traffic density. For this case, we have included an evaluation based on the regular labor days, as well as the weather conditions, which may provide an additional behavior to the traffic density.

An additional favorable aspect is that the hold system has been implemented using data mining and BI open source tools as Pentaho, which works with the process that involves extraction of meaningful information from huge databases, information that reveals business intelligence, through hidden factors, trends, and correlations that allows users to make predictions that solve problems associated with urban traffic congestion.

IV. CONCLUSSIONS

The objective of this research was the designed and implemented a low-cost Internet of Thing proposal, in order to monitor and analyze traffic circulation and provide potential solutions to reduce their associated negative and time-consuming effects. This designed and developed system of low-cost wireless monitoring, is supported on a distributed multilayer model. This system interacts with a device consisting of two electronic Arduino platforms, interacting in a master-slave mode, and which has a distance sensor based on laser for detection of vehicles. This in turn, has the ability to connect to the Internet transmitting in real-time data taken by HTTP requests over the cellular network. On the data collected we mounted an engine for data mining in order to obtain information about traffic on highways and then propose potential solutions. The proof of concept has been applied in the city of Quito, particularly over the two central lanes of the Simon Bolivar Avenue with unquestionable results, both in the operation of the software and hardware that compose the prototype, as well as reference measurement of traffic. Based on our results, the system manages and predicts to suggest and propose alternatives to lessen traffic congestion, fuel waste, and also air pollution.

As a potential future complementary study, we may focus on the improvement of the detection algorithm to enable the possibility to classify the type of vehicles according to their height, size, and weight. This would allow a more precise data base increasing and complementing the information that we have collected already in order to determine future favorable traffic behavior.

ACKNOWLEDGMENT

This work has been partially funded by Distributed System, Cybersecurity, and Content Research Group of the Universidad de las Fuerzas Armadas - ESPE in Sangolquí, Ecuador. All authors acknowledge the constructive reviews of the anonymous reviewers, who contributed constructively and favorably to this research.

REFERENCES

[1] Nellore, K., & Hancke, G. P., A survey on urban traffic management system using wireless sensor networks. *Sensors-MPDI*, *16*(2), 157.

[2] Jiang, J., & Claudel, C., A wireless computational platform for distributed computing based traffic monitoring involving mixed eulerian-lagrangian sensing. In Industrial Embedded Systems (SIES), 2013 8th IEEE International Symposium on (pp. 232-239). IEEE, (2013, June).

[3] Costanzo, A., An arduino based system provided with GPS/GPRS shield for real time monitoring of traffic flows. In Application of Information and Communication Technologies (AICT), 2013 7th International Conference on (pp. 1-5). IEEE, (2013, October).

[4] Magrini, M., Moroni, D., Palazzese, G., Pieri, G., Leone, G., & Salvetti, O., Computer Vision on Embedded Sensors for Traffic Flow Monitoring. In Intelligent Transportation Systems (ITSC), 2015 IEEE 18th International Conference on (pp. 161-166). IEEE, (2015, September).

[5] Wang, Q., Zheng, J., Xu, B., & Huang, Y., Analysis and experiments of vehicle detection with magnetic sensors in urban environments. In Cyber Technology in Automation, Control, and Intelligent Systems (CYBER), 2015 IEEE International Conference on (pp. 71-75). IEEE, (2015, June).

[6] Dessai, S. S. N., Development of Wireless Sensor Network for Traffic Monitoring Systems. International Journal of Reconfigurable and Embedded Systems (IJRES), 3(3), (2014).

[7] Perttunen, M., Kostakos, V., Riekki, J., & Ojala, T., Urban traffic analysis through multi-modal sensing. Personal and Ubiquitous Computing,19(3-4), 709-721, (2015).

[8] Pascale, A., Nicoli, M., Deflorio, F., Dalla Chiara, B., & Spagnolini, U., Wireless sensor networks for traffic management and road safety. Intelligent Transport Systems, IET, 6(1), 67-77, (2012).

[9] Fernández-Lozano, J. J., Martín-Guzmán, M., Martín-Ávila, J., & García-Cerezo, A., A wireless sensor network for urban traffic

characterization and trend monitoring. Sensors, 15(10), 26143-26169, (2016).

[10] Lee, J., Zhong, Z., Du, B., Gutesa, S., & Kim, K., Low-Cost and Energy-Saving Wireless Sensor Network for Real-Time Urban Mobility Monitoring System. Journal of Sensors, (2015).

[11] Jo, Y., Choi, J., & Jung, I., Traffic information acquisition system with ultrasonic sensors in wireless sensor networks. International Journal of Distributed Sensor Networks, (2014).

[12] Swathi, K., Sivanagaraju, V., Manikanta, A. K. S., & Kumar, S. D., Traffic Density Control and Accident Indicator Using WSN. Traffic, 2(04), (2016).

[13] Canepa, E., Odat, E., Dehwah, A., Mousa, M., Jiang, J., & Claudel, C., A sensor network architecture for urban traffic state estimation with mixed eulerian/lagrangian sensing based on distributed computing. In Architecture of Computing Systems–ARCS 2014 (pp. 147-158). Springer International Publishing, (2014).

[14] Mousa, M., Abdulaal, M., Boyles, S., & Claudel, C., Wireless sensor network-based urban traffic monitoring using inertial reference data. InDistributed Computing in Sensor Systems (DCOSS), 2015 International Conference on (pp. 206-207). IEEE, (2015, June).

[15] Singha, M. R., & Kalita, B., Using Mobile Phone Network for Urban Traffic Management. International Journal of Computer Applications, 65(2), (2013).

[16] Singha, M. R., & Kalita, B., Mapping Mobile Phone Network onto Urban Traffic Network. In to appear Proceeding of International Multi conference of Engineers and Computer Scientists, (2013).

[17] Elmotelb, A. S., Shabana, B. T., & Tolba, A. S., A Simulated System for Traffic Signal Management Based on Integrating GIS & WSN Techniques, (2016).

[18] Al-Sakran, H. O., Intelligent Traffic Information System Based on Integration of Internet of Things and Agent Technology. International Journal of Advanced Computer Science and Applications (IJACSA), 6(2), 37-43, (2015).

[19] Zhou, J., Chen, C. P., Chen, L., & Zhao, W., A user-customizable urban traffic information collection method based on wireless sensor networks.Intelligent Transportation Systems, IEEE Transactions on, 14(3), 1119-1128, (2013).

[20] Liang, B. J., Traffic flow detection based on wireless sensor network. Journal of Networks, 8(8), 1859-1865, (2013).

[21] Eren, H., Pakka, H. M. T., AlGhamdi, A. S., & Yue, Y., Instrumentation for safe vehicular flow in intelligent traffic control systems using wireless networks. In Instrumentation and Measurement Technology Conference (I2MTC), 2013 IEEE International (pp. 1301-1305). IEEE, (2013, May).

[22] Zhang, W., Tan, G. Z., & Ding, N., Traffic Information Detection Based on Scattered Sensor Data: Model and Algorithms. Adhoc & Sensor Wireless Networks, 18, (2013).

[23] Y. Xu, X. Song, Z. Weng, G. Tan. An Entry Time-based Supply Framework (ETSF) for mesoscopic traffic simulations, Simulation Modelling Practice and Theory, 2014, 47(6), 182-195.

[24] Doukas, C., Building Internet of Things with the ARDUINO. CreateSpace Independent Publishing Platform, Vol. 1, April 2012.

[25] Fuertes, W., Carrera, D., Toulkeridis, T., Gal, F., & Torres, E. (2015, October). Distributed system as internet of things for a new low-cost, air pollution wireless monitoring on real time. In 2015 IEEE/ACM 19th International Symposium on Distributed Simulation and Real Time Applications (DS-RT) (pp. 58-67). IEEE..

[26] Pereira, J. L., & Costa, M., Decision Support in Big Data Contexts: A Business Intelligence Solution. In New Advances in Information Systems and Technologies (pp. 983-992). Springer International Publishing, 2016.

[27] Vyatkin, V., Software engineering in industrial automation: State-of-the-art review. Industrial Informatics, IEEE Transactions on, 9(3), 1234-1249, 2013.

[28] Pressman R., “Software Engineering, A practicioner’s Approach”, Seventh Edition, Mc. Graw Hill, Higher Education, ISBN 978–0–07–337597–7, 2010.

[29] Beck, K., Andres, C., Extreme Programming Explained: Embrace Change. Second Edition. ISBN: 978-0321278654. Addisson-Wesley. USA. 2004.