Management System of Smart Electric Vehicles Using Software Engineering Model

Original Scientific Paper

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Abstract – *In this paper, a management system for smart electric vehicle is introduced using software engineering models and installed Sensor Network (SN). Two software engineering models are proposed to construct the information exchange and available resource management algorithms, in which the required performance of vehicles is obtained. The resource management algorithm adopts the LeNet-5 deep-learning model in choosing the best driving mode amongst suggested five modes. The dataset is achieved from the simulated SN. The results show the satisfactory performance of the electric cars in terms of information exchange and resource management. The Message Queuing Telemetry Transport (MQTT) broker server is employed for monitoring the information exchange between the sensors, actuators and controller. The delay time is measured to be less than 1 sec for transmitting 1000 message. The proposed system saves energy by 1-8 kWh and a storage capacity by 9-95 MB for driving 100 km.*

Keywords: *Software Engineering, Electric Car, Sensor Network, Deep-Learning*

1. INTRODUCTION

The changing of energy resources from oil based ones to the renewable energy resources forces the car factories to turn up with the electric cars. These cars face different challenges that should be tackled to accommodate the industry in right way. These challenges include the consuming of the electrical energy and related factors that affect the performance of cars. Moreover, the presented cars should come up with smart technique in managing them throughout different circumstances. The Sensor Networks (SN)s are utilized to offer the smart touch in addition to the real-time monitoring to the surrounding circumstances of the cars. The use of these techniques provide the electric car with smart management in terms of reading the sensors and taking the suitable actions. Moreover, the Artificial Intelligent techniques, such as machine learning and deep-learning are widely used with the SN for optimizing the solutions [1]-[5].

The energy saving in the electric car represents an important point of well industry. This is due to the limitation of used batteries in energy abilities. Therefore, different research works were introduced to propose numerous methods in energy reduction. The energy reduction methods focus on the common point, which is the reducing of facilities and properties of the car and the actuation actions [6].

The information exchange between the car sensors, actuators, and controllers is allocated at the high priority consideration. It should be controlled by a suitable protocol, such as Message Queuing Telemetry Transport (MQTT). In addition to the used protocol, an algorithms are also built to manage the readings scheduling and the processing procedures [7]. At the other hand, the software engineering models are widely used in the designed systems for increasing different factors, including reliability, expandability, and so on. In the car system, it is important to design the management algorithm based on the software engineering models to guarantee the mentioned parameters above. Moreover, the proposed algorithms consider the required conditions that should be available as well as the actuation actions in the electric cars [8]-[10].

In this paper, software engineering models are presented to be adopted in designing the data exchange and resource management algorithms for electric cars based on SN. The SN is installed in wired connection over the parts of electric cars throughout the controller. The data exchange algorithm manages the reading and actuation actions exchange over the SN. While the proposed resource management algorithm focuses on minimizing the consumed energy and storage capacity through the work of electric cars. This is done by applying the proposed software engineering model and driving modes that are varied from economy to costly. The deep-learning model is used in selecting the suitable driving mode based on the sensor readings. This model is trained using a dataset, achieved from the SN simulation using MATLAB. The achieved results show the efficiency of the proposed algorithms and the effect of software engineering model on the system performance. There are noticed enhancements in the data exchange, as well as the consumed energy and storage capacity.

2. RELATED WORK

Due to the importance of developing the industry of electric cars, numerous researchers interested in providing models that tackled different visions of facing problems. The authors of [11] presented a deep review study on the provided energy management methods for hybrid electric vehicles. Moreover, different optimization algorithms have been studied to point out the solutions for the appeared issues. In [12], a real-time energy management system for hybrid electric vehicles using Adaptive Equivalent Consumption Minimization Strategy. The designed controller collected the information for trips and concluded the optimal way in consuming the energy for each trip in future. The system was evaluated and compared with the traditional methods, such as charge depleting charge sustaining, and the results showed the superior performance of the proposed system. Whilst, a comprehensive review has been presented in [13] to cover the solutions for the energy management of electric cars. These solutions included the artificial intelligent tools and other optimization methods. The review focused on two points: review on energy management systems, and optimal solutions, introduced based on the facing problems.

In [14], the authors also introduced a review on the problems of energy optimization in the electric cars as well as the solutions and presented algorithms. In addition, the simulation prototype for energy management of electric cars has been proposed in [15] using dynamic programming and receding horizon. The controller in the simulation obtained a partial information of each planned trip from the user and the old information for similar trips to evaluate the required amount of charging and fuel. This could reduce the consumed energy by 10% according to the simulation results. The authors of [16] proposed a fuzzy logic based controller that minimized the consumed energy of the Hybrid cars using instantaneous Degree of Hybridization. The proposed controller balanced between the electric and fuel engines in driving the cars. The results were studied for different modes of driving to clarify the effects of the proposed controller on the energy consuming.

In [17], mathematical and simulated models have been proposed for designing the controller that managed the consumed energy by the electric cars. The analysis of the proposed models proved the well management of the system of the available resources. In [18], a trade-off formulation was presented in controlling the fuel amount and energy required for driving hybrid cars in specific routs. Different optimization algorithms have been employed in producing the car system for economy driving mode. The authors of [19] proposed a gateway convertor between Alternating Current (AC) and Direct Current (DC) power that controlled the charging and discharging batteries as well as the balancing between power generating and consuming. The simulation results showed the recorded efficiency of the proposed system in terms of batteries charging/discharging and power consumption management. A dynamic programming method was adopted in presenting an optimized rule-based strategy for reducing the consumed power of electric cars [20]. The optimization method adopted the collected data from the cars to decide the optimal way of saving the power with satisfactory level of driving. Moreover, numerous optimization methods have been used in [21] to reduce the consumed power in hybrid vehicles. All these methods were employed in real-time environment to compensate the drawbacks of the traditional methods.

In [22], an education based platform of electric cars was proposed. It was built based on software engineering models. This model was designed for minimizing the consumed power in electric cars using optimization methods. The authors of [23] presented the challenges that faced the designing of electric cars in terms of the used embedded and software systems. One of the most tackled challenges was the batteries life-time and charging capacity. Additionally, it considered the unexpected problems that might appeared throughout the performance and driving of the cars.

In [24], five preconditions were presented for obtaining the best data management in the electric cars. The data management was important to control the changes in the car system due to the surrounding circumstances including the land shape and modes of driving. The authors of [25] introduced a review on the analysis of data in the electric cars. These data covered the internal and external environments. The internal dealt with the monitoring data of power, fuel, engine, etc. While the external data included the infrastructure of the system, such as power stations, road data, trip data, etc. In the same way, the authors of [26] adopted the data management for different applications to achieve the required aim in efficient approach

3. PROPOSED RESOURCE MANAGEMENT SYSTEM

The propose resource management system for electric cars has been built using different techniques including the software engineering models that is used for designing the software algorithms for data and resource management. The SN is adopted in the proposed system to monitor the parts and behavior of electric car. It contains sensors to measure temperature of engine and weather, acceleration, weather moisture, air pressure, energy, Ultra Violet (UV) detection, around car detection, and speed. Weather temperature and moisture are used for providing this information to the driver. Moreover, a Raspberry Pi4 can be used as a controller due to its ability in performing the algorithms in sufficient and reasonable real-time. The core frequency of Raspberry Pi4 reaches 1.8 GHz that provides the system with high speed processing, which is satisfied to the proposed prototype. In addition, the consumed energy of this component is suitable (3.8-4 W) for designing the proposed system.

Figure 1 explains the block diagram of the proposed system in terms of SN. From this figure it can be seen that the SN is based on the central control with planned distribution of sensors. The sensors with their functions are represented in the block diagram and they are connected to the central controller. At the same time, the sensors are connected together to pass the data throughout the gateway of each sensor node. This connectivity between sensors offers the guarantee of delivering the data for each sensor to the controller in case of a faults appeared in communication of such sensor. Each sensor is a node with processor, memory, battery, and communication unit (gateway).

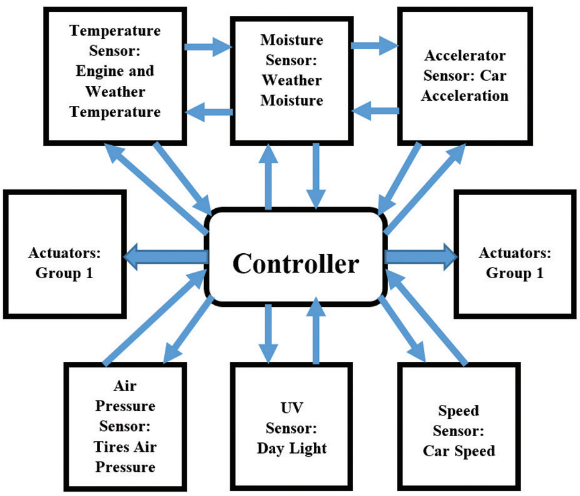

Fig. 1. SN structure

In order to ease the reading flow, this section is divided into two main parts as follows.

3.1. SOFTWARE ENGINEERING MODEL FOR DATA EXCHANGE

As mentioned above, the SN is adopted in sensing the change in the surrounding circumstances of the electric car. Due to the use of SN, there is a need for managing the data exchange between sensor nodes and the controller. Basically, the MQTT protocol is adopted in managing the data transmission over the SN. Meanwhile, there is another need for managing the work of each node that can be presented in Figure 2 as a software engineering model using state diagram for data exchange between a sensor node with another one or controller as well as the required actuators. From Figure 2, the software engineering model manages the following points:

- ***Sensor Node***: The presented model represents the state of each sensor node that prepares the data message of the readings from the sensor to be sent for the controller every 30 sec. This time is selected as we assume that there no risky change in readings within it. The readings in the data message are exchanged with the controller and the near nodes that works as gateways for double check that the readings are safely received by controller. The exchange is done in two ways (transceiver) for sending the data messages and receiving acknowledgments, represented as feedback arrows, from controllers or any other orders of turning ON/OFF or repeating the readings. Each sensor node has its own feedback for correcting the faulted readings and ensuring the validity of data message.
- ***Controller***: It is the main part of managing the electric car. It receives the data messages from all sensor nodes throughout the MQTT routes and manages this process for preventing any loss in the sent data messages. This data is processed and then the required actions are decided by the controller to be sent for actuators or sensor nodes. The controller has a self-feedback for correcting the produced decisions based on the received data. This can guarantee the validity and availability of the resources in the management system of the electric cars.
- ***Actuators***: This part is responsible on performing the decisions, come from controller, in an efficient way. The cycle loop between the actuator and controller can prevent any error in actuating the decisions.

It is important to note that the software engineering model offers further features to the data exchange algorithm rather than using just MQTT protocol. This model provides the algorithm with availability, integrity, and validity. These features increase the reliability of the algorithm and reduce the faults.

3.2. SOFTWARE ENGINEERING MODEL FOR RESOURCE MANAGEMENT ALGORITHM

In electric car systems, the available energy and storage size are considered as important resources that should be managed well. The reducing of the consumed energy provides the cars with longer battery life that can reflect positively on the crossed driving distances. At the other hand, the data storage capacity is tackled due to importance of storing the sensor readings for a specific period of time for system evaluation purpose. In this paper, the software engineering model is proposed to design the resource management algorithm that addresses the issues of consumed energy and storage. Figure 3 represents the proposed software engineering model for the resource management algorithm using state diagram. The working steps of the proposed algorithm can be summarized as:

- ***Energy Source:*** In the electric car, the battery unit provides the energy to all parts of cars, including sensor nodes, engine, lights, and so on.

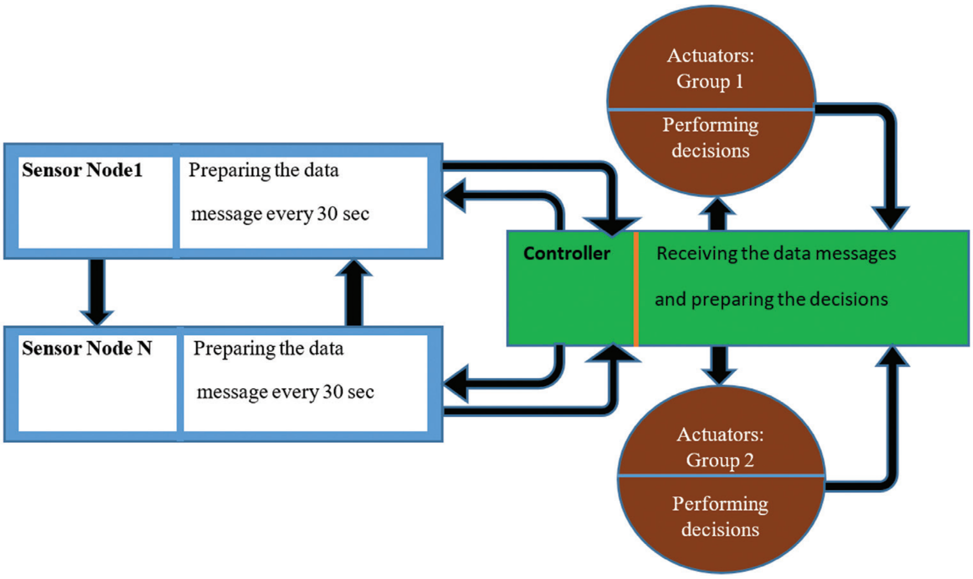

Fig. 2. The proposed data exchange algorithm represented as a software engineering state model

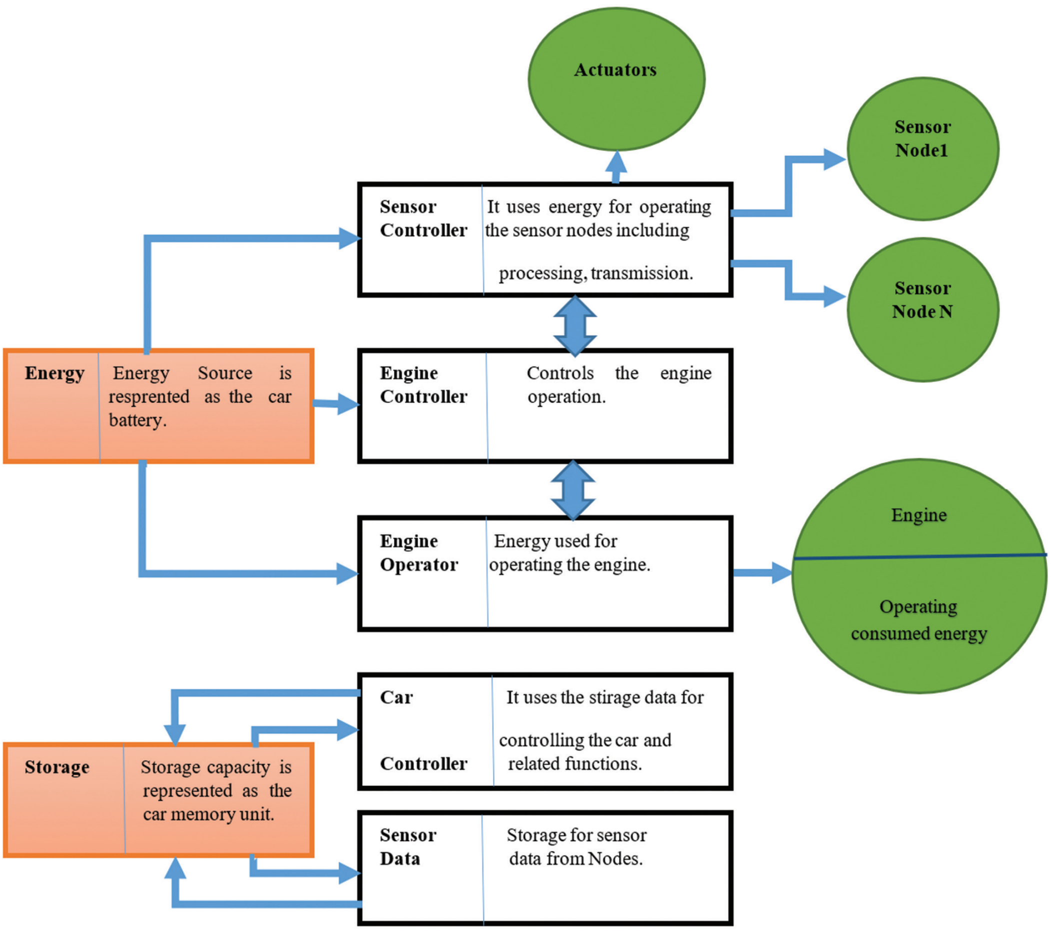

Fig. 3. Software engineering model for resource management algorithm

- ***Sensor Controller***: It is a part of the main controller of electric car. To control the operating of sensor nodes, each one has a controller that manages the operation, storage, processing and data transmission. This reflects on the amount of consumed energy, which is the results of readings flow process of the sensors. The sensor is turned on/off depending on the need of the system to avoid the continuous working and consuming energy, as it requires processing storage and transmission. The same procedure is applied on actuators, such as lights, glass wiper motors, and so on. The need of operating sensors depends on the current case. For example, the lights should not turn on in a day time and the wipers as well in a sunny day. In addition, the transmission of data is performed in different period based on the circumstances to prevent keep sending the same data. The decision of sending readings (data) to the main controller is taken when a change to them is occurred. This can save a valuable energy amount as the data transmission consumes most of available energy for sensors.
- ***Engine Controller***: It is a part of the main controller of electric car. This unit provide the engine with operation statuses. These statuses include the driving mode, speed, acceleration, and load balancing. The control signals are sent to the next unit that is engine operator.
- ***Engine Operator***: As a part of the main controller, it is responsible on operating the engine by generating a pulse width modulation based signal to the major engine motors.
- ***Storage Capacity***: Each electronic part of the electric car system contains a memory unit. All these units are combined in the storage capacity that saves the reading of sensor nodes and the decisions of the car controller for a period of time, in this case one weak. After that, the new data is over written on the old stored information.

3.3. INTELLIGENT DECISION MAKING MODEL

The main controller takes important decisions regarding the status of managing the electric cars. The deep-learning model is employed to obtain the right driving mode of the car. This model is performed in the main controller unit of the electric car. Each selected driving mode controls the operating of all cars including engine, sensor nodes, and actuators. The deep-learning model classifies the collected sensor reading into decisions (classes) of driving modes. This model is trained using the collected dataset from the sensor network of a car that includes 2.52 million records as explained in the next section.

The deep-learning model of LeNet-5 architecture [27] is adopted. This model is shown in Figure 4 that explains the deep-learning stages and layers, such as convolutions, subsampling, full connection and Gaussian connections. Some changes have been done on the LetNet-5 in terms of changing the two dimensions input to one dimension to be compatible with the dataset of the adopted sensor network of electric car.

In this paper, six driving modes are adopted to be as classes in deep-learning model. These modes are explained in Table 1. From this table, it is shown that the modes explode the sensors and actuators in different ratios. Each mode uses the sensors and related actuators depending on the weather, time, and land shape and varies from 0% to 100%.

In mode A, the car is turned off and all parts of car are powered off. Mode B is the economy one that offers the basic conditions of driving the car in safe in day time with suitable weather and land conditions. The difference between mode B and mode C is that the last considers the acceleration property that provide the car with more engine horse energy. This is used for speedy drive and hell land shapes. Mode D represents the driving in mode C in summer time, where the air conditioner is on. This mode needs more energy for operating the related sensors and actuators. In Mode E, the driving is in night time with good weather condition and hell land. This mode consumes more energy due to the use of lights. Mode F is the most consumed energy one due to the use of all properties of electric car with raining and bad land shape. The selection of the suitable mode is based on the readings of sensor nodes that are sorted in upper and lower thresholds for each. Table 2 lists the considered thresholds of each mode.

4. DATASET

As mentioned in the early section, the deep-learning model is trained using the prepared dataset. It is prepared by collecting the data readings of sensors from the constructed sensor network of the electric car, shown in Figure 1. The dataset represents the run work of the network that is simulated using MATLAB environment. The MQTT protocol is adopted in this sensor network for managing the data exchange. The reading data of each sensor is considered as a feature for the deep-learning model. Therefore, six features are the input of dataset to the model. Different case studies have been employed for covering the possible changes in the car system, surrounding circumstances, and energy consuming. Table 3 is the summary to the collected dataset that is represented in different numbers of records for each mode. Some of records are not valid in terms of data structure of sensor readings due to delays, data corruption, and packet loss. Thus, these records are excluded from the valid dataset. The dataset is divided into training by 70% and test by 30% samples. Validation Ratio is computed as:

$$Validation\ Ratio = \frac{No.of\ Valid\ Records}{No.of\ Records} \tag{1}$$

It is important to keep in mind that each driving mode is formulated as a class in deep-learning model that is used later in selecting the suitable mode that can save more energy and storage capacity rather than exhausting the resources in single one.

5. RESULTS

The proposed resource management system for electric car is simulated in MATLAB environment to be tested under different case studies to measure the obtained energy saving and storage capacity by employing the proposed software engineering model based resource management algorithm that adopts the deep-learning model in selecting the suitable driving mode. Moreover, the data exchange between the sensors and controllers is managed using the proposed software engineering model based data exchange algorithm.

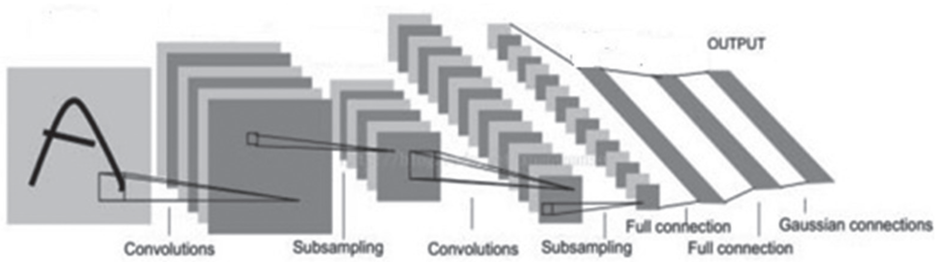

Fig. 4. The LeNet-5 architecture [27]

Table 1. Driving mode specifications

No.	Mode Name	Specifications							Sensor Efficiency	Actuator Efficiency
		conditioner	Lights	Engine	Cooling system	Wiper	Radars	Acceleration		
1	Mode A	Off	Off	Off	Off	Off	Off	Off	0%	0%
2	Mode B	Off	Off	On	On	Off	On	Off	40%	30%
3	Mode C	Off	Off	On	On	Off	On	On	50%	50%
4	Mode D	On	Off	On	On	Off	On	On	60%	70%
5	Mode E	On	On	On	On	Off	On	On	90%	90%
6	Mode F	On	On	On	On	On	On	On	100%	100%

Table 2. Sensors thresholds for selecting each driving mode

Mode	Engine Temperature Co	Weather Temperature Co	Speed km/H	UV detector	Moisture	Accelerator m/sec2
Mode A	0-20	0-60	0-2	0-100%	0-100%	0-1
Mode B	>50	0-25	>5	>20%	<90%	<10
Mode C	>50	0-25	>50	>20%	<90%	>10
Mode D	>50	>25	>50	>20%	<90%	>10
Mode E	>50	>25	>50	<20%	<90%	>10
Mode F	>50	>25	>50	<20%	>90%	>10

Table 3. Dataset records for each driving mode

Driving mode	No. of Records	No. of Valid Records	No. of Invalid Records	Validation Ratio
Mode A	500000	500000	0	100%
Mode B	500000	430000	70000	86%
Mode C	500000	390000	110000	78%
Mode D	500000	300000	200000	60%
Mode E	500000	480000	20000	96%
Mode F	500000	420000	80000	84%
Total	3000000	2520000	480000	84%

The software engineering guarantees the reliability, validity and flexibility of the proposed algorithms.

The MQTT broker has been adopted in monitoring the proposed data exchange algorithm performance between nodes as clients and broker server. The achieved results show that the investigated sensor network in electric car works in efficient manner, where over 1000 messages have been sent and the delivery time is less than 1 sec. These messages from six sensor node (clients) to the broker server under a common Quality of Service (QoS).

At the other hand, the proposed resource management algorithm uses the deep-learning model. Thus, the deep-learning model is tested to prove the validity of accuracy in terms of training and test modes. Figure 5 shows the training accuracy of the presented deep-learning model, while Figure 6 illustrates the testing accuracy of the deep-learning model. Both of training and testing accuracy and loss is changed and enhanced with the increasing number of epochs. This is due to the minimizing the error in building the weights for the training and testing output. The maximum obtained training accuracy is achieved after 100 epochs to be 99.2%, while the testing accuracy reaches the maximum value after 100 epochs to be 98.3%. These results prove the high efficiency of the introduced deep-learning model in classifying (selecting) the suitable driving mode.

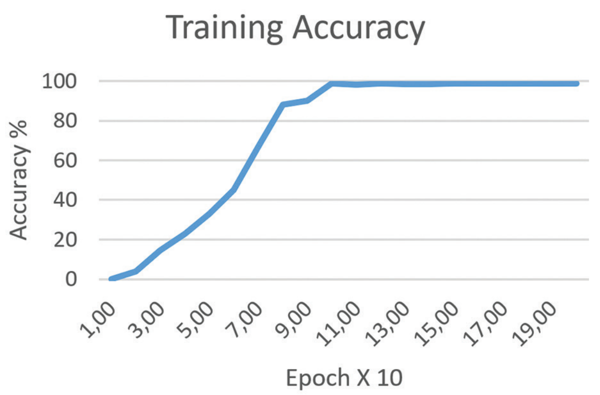

Fig. 5. Training accuracy vs. epochs

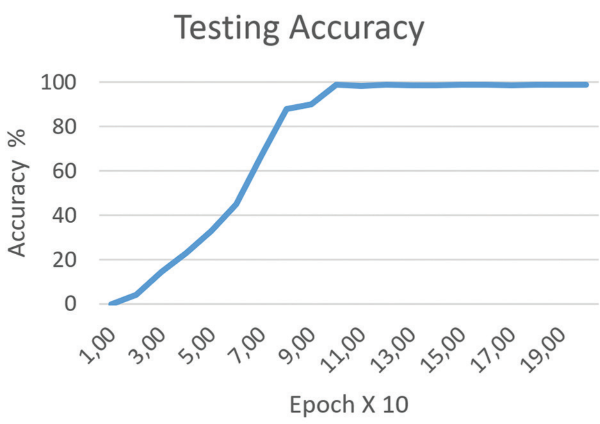

Fig. 6. Testing accuracy vs. epochs

In order to measure the saved energy using the proposed software engineering based resource management algorithm, the investigated system's driving modes are compared with the traditional electric car model in Figure 7. The traditional model consumes 15 kWh to cross 100 km distance. From this figure, it is appeared the superior performance of the proposed system in saving energy that can gain more than 8 kWh in Mode A, while this gain is reduced with the employed modes till reaching 1 kWh in Mode F. The last one is close to the traditional model due to the use of all car option, but the 1 kWh is gained from the use of proposed algorithms that manage the resources well.

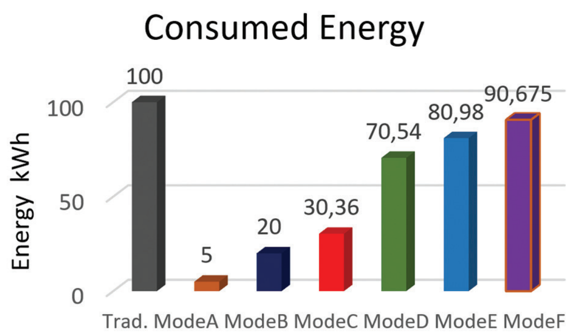

Fig. 7. The consumed energy vs. driving mode for 100 km distance

The consumed energy in kWh is computed using the following formula:

$$Energy = \frac{Total\ enrgy}{Speed} \times Distance \tag{2}$$

Where, Total energy means the available energy in electric car in kW, the Speed is measured by km/h, and the crossed Distance is in km. At the other hand, Figure 8 shows the saved storage capacity of the considered modes in comparison with the traditional electric car model. The traditional model is assumed to consume 100MB of storage for saving data of sensor readings and controller signals. The achieved saving in capacity is varied from 9-95 MB for driving distance of 100 km. The enhancement in the proposed system is the results of employing the proposed data exchange and resource management in efficient way throughout the considered driving modes.

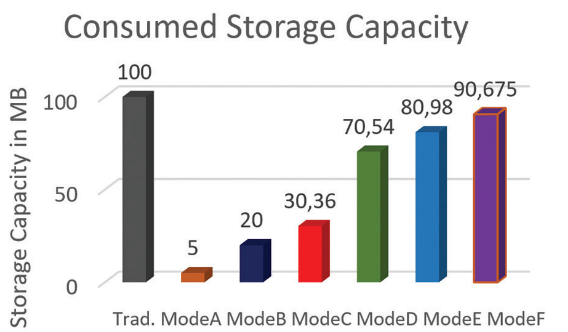

Fig. 8. The consumed storage capacity vs. driving mode for 100 km distance

To ensure the satisfied performance of the proposed system in selecting the suitable driving mode, Table 4 explains the training accuracy ratio of successful choosing of the mode. Each driving mode has trained (by injecting the sensor reading within the related thresholds) 100 times. It is clearly shown that the obtained accuracy ratios are involved in the testing accuracy of deep-learning model with 98.8%.

Table 4. Training accuracy for injected readings over the driving modes

Driving Mode	Number of Training	Successful Selecting	Failed Selecting	Accuracy Ratio
Mode A	100	98	2	98%
Mode B	100	99	1	99%
Mode C	100	98	2	98%
Mode D	100	97	3	97%
Mode E	100	98	2	98%
Mode F	100	99	1	99%

6. CONCLUSIONS

A resource management system for electric cars was proposed based on software engineering modelling. This system adopted two main algorithms: data exchange and resource management. The first one combined the software engineering model and MQTT protocol in order to enhance the performance in data exchanging between sensor nodes and controller. The second algorithm tackled the problem of reducing the consumed energy and storage size by employing the suitable driving mode based on the sensor readings. It used the deep-learning model in selecting the best driving mode depending on the fed sensor readings. The deep-learning model was tried and validated using the prepared dataset, obtained from the employed sensor network. The achieved results showed the superior efficiency performance for the proposed system. The MQTT broker server was used for monitoring and evaluating the data exchange algorithm. While the saved energy and storage capacity were measured in the applying of the resource management algorithm. In addition, the deep-learning was tested in terms of accuracy for training and validation. A hundred test sample have been considered in evaluating the proposed system for each driving mode and the results proved that the accuracy was over 98%.

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