UNIVERSITATEA DIN PETROȘANI

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PHD THESIS

SUMMARY

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UNIVERSITY OF PETROSANI
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CONTRIBUTIONS REGARDING THE USE OF ELECTRIC VEHICLES IN CLOSED SPACES

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Introduction

The extraordinarily rapid technological developments of recent years can be found more and more in the car manufacturing industry, managing to create vehicles that a few years ago we did not even dream of, today's cars are becoming more and more similar to complex systems of sensors and transducers as well as computer systems for management and control of all functions. Thus, these technological advances as well as the concerns in recent years regarding the major impact of vehicles with internal combustion engines, fuelled by fossil fuels, on the environment and implicitly on our lives, have opened several directions of research regarding the design and realization of electric vehicles that do not directly pollute.

According to specialized studies, road transport is the main cause of air pollution in the big cities of the world and implicitly also of Europe, where more than 400,000 citizens die prematurely every year and millions of other people have respiratory and cardiovascular diseases as a result of the inadequate quality of the air. Road transport is responsible for around 40% of emissions of nitrogen oxides (NOX) in Europe, the majority of which comes from diesel-powered internal combustion engine vehicles. Electric vehicles do not emit CO2 and have significantly lower indirect pollutant emissions than conventional vehicles. Even though electricity production also generates pollution, as power plants are usually located far from cities, the pollution they cause has a lower impact on human health than pollution from conventional vehicles. So, although in order for an electric vehicle to be 100% non-polluting, the best solutions should still be found regarding all the constructive elements that, in the process of making, may emit polluting factors and the recharging of their batteries should be done by means of electricity production facilities using renewable energy sources (photovoltaic, wind), this type of vehicle is increasingly common in everyday life, especially in large urban agglomerations, and could contribute up to 43% to reducing carbon dioxide emissions compared to a classic vehicle with an internal combustion engine powered by gasoline, diesel or other hydrocarbons. Another special characteristic of electric vehicles is that represented by their small dimensions, thus making them ideal candidates for various applications inside private or industrial facilities. Due to the fact that they do not emit pollution directly and are generally small in size, electric vehicles are found more and more often in industrial halls, factories and other industrial premises either as vehicles with the help of which various goods are handled or as a means of transport.

So, starting from the ideas mentioned above about the ever-deepening concerns about finding the best solutions to reduce the pollution resulting from the impressive increase in the number of vehicles on the streets of big cities and from the new concepts and achievements in electric vehicle technology defined the overall framework for the development of an adaptive electric vehicle with intelligent functions. The research presented in this doctoral thesis fits perfectly into the current concerns regarding the realization of small electric vehicles with intelligent capabilities that can be used in closed industrial spaces or as mobile platforms for monitoring some environmental parameters due to the lack of any direct emission of pollution that could influence or alter the values of those parameters.

The main objective of this doctoral thesis is the design and implementation of a system that integrates electric vehicles, a communication network suitable for use in closed industrial spaces and a system for locating vehicles in this type of space as well as a system for mapping usable for the realization of autonomous driving algorithms.

Based on the general objective, 4 major objectives were defined as follows:

OB.1.: Design of the actuation and driving part for an electric vehicle

OB.2.: Design and implementation of the communication system and the localization system

OB.3.: Integration of sensors within the functional structure of the electric vehicle

OB.4.: Realization of the practical implementation of the entire constructed system.

The doctoral thesis is structured in an introductory chapter, a chapter presenting the research methodology, three chapters of theoretical and applied content, a chapter of conclusions, contributions and further developments as well as a chapter with bibliographical references relevant to the research.

Chapter 1 - The current state of research in the field of electric vehicles

In this first chapter of the doctoral thesis entitled ***Contributions regarding the use of electric vehicles in closed spaces***, a brief introduction is made regarding the history of electric vehicles, presenting the fact that the first vehicle of this type in its rudimentary form was made around 1828. Between 1828 and 1835, more and more small electric vehicles appear. The years 1889-1891 bring incredible success in the development of these vehicles to the United States of America. The peak of that period in the development of electric vehicles is reached between 1900 and 1912. The period 1920-1935 is considered the decline point in the electric car industry with the discovery of oil. The oil price crisis of the 1970s brought back the development of vehicles powered by electricity, but this trend did not last long due to the multiple disadvantages of electric vehicles compared to vehicles with internal combustion engines. The 1990s, with new regulations on finding ways to reduce pollution, create a new point of interest for the development of such vehicles. The technological advance in the development of all the constructive elements of an electric vehicle and the growing concerns about the increase of greenhouse gas emissions are still maintaining the trend towards the intensification of the realization and widespread use of electric vehicles.

Even though the United States of America, along with China, are considered pioneers in the electric car industry, Europe is also seeing an increase in interest in electric vehicles. The majority of EVs on the road are concentrated in several northern and western European states, although southern and eastern Europe have recently seen the greatest sales growth.

According to specialist analyses, it can be seen how the electric vehicle market in Europe has started to grow steadily since 2018. Globally, between 2010 and 2021, more than 17,607,610 electric vehicles were sold and put into circulation, both pure electric as well as electric plug-in hybrid vehicles. The record for the sale of electric vehicles was reached in the year 2021 when, despite the Covid -19 pandemic and the problems caused by it in the entire manufacturing process, more than 120,000 electric vehicles were sold per week. The market for electric vehicles has started to grow in Europe also amid awareness of the harmful effects that greenhouse gases can have. Despite technological improvements, transport is still responsible for around a quarter of Europe's greenhouse gas (GHG) emissions, which contribute substantially to climate change. While in other sectors, GHG emissions have gradually declined since 1990, those in transport only started to decline in 2007 and remain high. In the transport sector, road transport is by far the most polluting, accounting for around 80% of all EU transport GHG emissions.

The EU's target is to reduce GHG emissions by at least 40% below 1990 levels by 2030. For transport in particular, the aim is to reduce GHG emissions by 60% compared to 1990 levels by 2050.

In this chapter, a presentation of the current stage of the development of electric vehicles is made, making a review of the most important specialized works in the field that highlight the fact that such a vehicle could contribute up to 43% to the reduction of carbon dioxide emissions compared to a classic vehicle with an internal combustion engine powered by gasoline, diesel or other hydrocarbons. The most important challenges in the electric car industry are presented and the actions that should be taken by political decision-makers regarding the development of this segment of transport are highlighted. Much of the specialized literature also studies the technologies related to the development of electric vehicles and also deals with the social and economic side of this new concept of sustainable development in the field of transport. After an analysis of the research on the modelling, design and realization of all the elements found in an electric vehicle, new perspectives for the future are also presented as it results from the current research studied.

The chapter continues somewhat naturally on the current trend so that, after presenting the notable achievements about the entire electric vehicle technology, it moves on to present some research on autonomous electric vehicles. The concept of an autonomous vehicle is presented and a classification is made of the types of automation found in an electric vehicle. Autonomous electric vehicles represent the natural transition in the current context towards the creation of a 100% autonomous vehicle that can run without the intervention of a person, can make quick decisions and adapt to any sudden change both in terms of the driving environment and its own operation, all these things taking place on a general background of sustainable development. Autonomous vehicles are those vehicles that, with the help of sensors, can take data from the environment, understand them so that they can then act accordingly. These types of vehicles are guided by three essential principles: sense, thought and action. At the moment there are no 100% autonomous vehicles that do not need at least the presence of a person who can intervene in case of danger. Are presented, with references to many specialized works, the main functional characteristics of an autonomous vehicle as well as the multiple hardware and software systems that must be integrated in an electric vehicle for it to become autonomous. So, starting from the ethical issue of this new field of research that emphasizes how much or how little a driver of a vehicle will allow him to make different decisions and who will be responsible for them and until the realization of the whole operating algorithm of an autonomous electric vehicle, a series of outstanding scientific achievements are presented. Various operational models for the simulation, implementation and operation of autonomous vehicles are presented and several auxiliary systems found in these types of vehicles are described.

The creation of a small electric vehicle that can be used as a viable alternative to classic vehicles with internal combustion represents both for Romania and for the University of Petroșani a point of real interest in the attempts to bring added value in research on the development of sustainable transport alternatives.

From the analysis of all the specialized works studied and described in this chapter, it is observed that the field of using electric vehicles with autonomous navigation in closed spaces has not been sufficiently addressed in the research and it is proposed to adapt the driving models studied to the particularities of navigation in closed spaces.

From the study of the specialized literature, the aim of the research results, the design of a system that integrates electric vehicles and a communication network with the possibility of localization in closed spaces.

Chapter 2 - Research methodology

It presents in detail the support tools used and the activities performed to achieve the research goal. The stages of design, modelling and simulation in Matlab Simulink are presented as well as the stages of implementation of each subsystem within the general assembly of the electric vehicle with intelligent capabilities.

This doctoral thesis with the title ***Contributions regarding the use of electric vehicles in closed spaces*** falls within the field of applied scientific research and the subject of this chapter of the research methodology responds to the general objective and derived objectives. The research in this thesis aims to provide relatively easy to implement solutions to solve the identified problem, namely the creation of an intelligent electric vehicle that can be used in normal or autonomous driving mode inside closed spaces. To achieve this objective, this doctoral thesis presents in detail all the stages of design, modelling, simulation and implementation of software and hardware concepts regarding the electric drive part of a vehicle, its integration in a sensor network, the creation of a communication protocol and a localization system ready to be used inside closed premises such as industrial halls.

The research presented in this PhD thesis fits perfectly into the current concerns regarding the realization of small electric vehicles with intelligent capabilities that can be used in closed industrial spaces. After consulting several articles from the specialized literature that were presented in the first chapter of this doctoral thesis and that presented the current state of development of intelligent electric vehicles, some with autonomous driving capabilities, it was concluded that there are not many references regarding the driving of a

small electric vehicle inside closed industrial premises. Observing this research niche that is still too little studied both at the world and at the national level, several specific objectives were formulated to carry out this research.
The general objective of this doctoral thesis is the design and realization of a system that integrates electric vehicles, a communication network suitable for use in closed industrial spaces and a system for locating vehicles in this type of space as well as a usable mapping system for autonomous driving.

Operational objectives:
O1. Identifying the current status of the use of electric vehicles (applications, research directions addressed)
O2. Design of drive and driving part for an electric ATV
Specific objectives:
O2.1. Choice of drive system. Modelling and simulation
O2.2. Driving the motor through an algorithm based on the theory of distributions
O3. Communication system design
Specific objectives:
O3.1. Design and manufacture of LoRa communication devices
O3.2. Design of indoor LoRa localization system
O4. Integration of sensors in the electric ATV system with LoRa
Specific objectives:
O4.1. Identifying LIDAR mapping solutions
O4.2. Identifying solutions for environmental recognition
O4.3. Identification of sensor types for the analysis of environmental parameters
O5. Realization of practical application within a closed space investigation system

Chapter 3 - The design and realization of the electric vehicle

The main objective of this chapter was the realization of an electric vehicle starting from the choice of the functional platform on which it was worked, the modelling and simulation of the actuation element, the modelling and simulation of the command and control module, the presentation of the defining elements of the theory of distributions used for the control part and the actual implementation of a reliable solution. So, after choosing the platform of an ATV type vehicle (all-terrain vehicle), its entire mechanical structure was modified to allow the installation of an electric motor as a drive element.

The first drive system designed and realized in the first stage of the research used an induction motor fed at an alternating voltage of 220V as a drive element, the motor control system being formed by a voltage inverter that transforms the supplied 12V DC voltage of a battery in an AC voltage of 220V required by a frequency converter. With the help of the frequency converter, it was possible to control the entire drive system by implementing simple operating algorithms. Although we could say that the realization of a small electric vehicle capable of running on several types of terrain was achieved, the power supply and drive system presented many energy losses due to the multiple conversions of the supply voltage, and so the research turned to finding a way to feed the same motor at a much lower voltage obtained with the help of several 12V, 40Ah car batteries chosen especially for their low individual dimensions and weight, which is also important to obtain an electric vehicle with a low overall weight.

The first step towards achieving this new goal was to rewind the induction motor so that it could be powered at a low voltage, electrical voltage obtained using a number of 8 car batteries of 12V, 40Ah each weighing about 10 kg. In order for the rewinding process to have the expected result, the catalogue data of the used induction motor was entered and its functional characteristics (rotor resistance, stator resistance, rotor inductance and stator inductance) were modified in Matlab Simulink in order to find the best suited values so that these values can then be used in the rewind process. The mathematical model of an induction motor known for its reliability was established, starting with the establishment of the input-state-output matrix equations in order to then determine its mechanical characteristics.

After implementing the simulation equations of the induction motor in Matlab Simulink, a modular structure of the entire simulation program was created, creating six subsystems, each of which represents a functionality defined by the equations defined above. Thus, the simulation subsystems of the rotor, stator, Clark and reverse Clark transformation are highlighted, as well as the subsystem that allows viewing the torque/speed output graph. There were chosen as the supply voltage 6 car batteries of 12V, 40Ah connected in series thus obtaining 72V. The operation graphs of stator flux, rotor flux and torque and speed diagrams for the proposed motor supplied at the voltage of 72V were observed. Good results were obtained and, after analysing the obtained results, it can be stated that the simulation model is a valid one observing the functional behaviour of the studied induction motor. After about 2.5 seconds from the initialization of the start sequence of the induction motor, it reaches a speed of about 1500 revolutions/minute and the moment stabilizes around the value of 12Nm. So, using this induction motor simulation model, families of mechanical characteristics could be drawn for different particular cases: different supply voltages (60V-96V), different values of stator and rotor resistance, different values of stator and rotor inductances as well as for different frequency values (40Hz – 60Hz).

Next in this chapter, the general elements of the theory of distributions were presented, which are in fact linear and continuous functions defined on a fundamental space that can be used to mathematically represent any model associated with reality. Then, using the properties of the theory of distributions, a mathematical and simulation model of a controller that can control an induction motor was created, thus obtaining an original approach in this field. The actual implementation of the entire control system was achieved with the help of IGBT modules implementing in a controller designed and made in the laboratory of the University of Petroșani all the elements analysed and discussed during the chapter. A small electric vehicle controlled with the help of a controller developed based on the theory of distributions operated with the help of IGBT modules capable of running on several types of terrain was thus obtained.

Chapter 4 - LoRa Sensor Network Design

In this chapter of the PhD thesis, different communication protocols used in wireless sensor networks were presented with a particular emphasis on the LoRa network and the LoRaWAN communication protocol. Thus, using the specialized literature by consulting several works that describe in a wide manner different wireless communication protocols, it was possible to synthesize the research in the field, thus creating an overview of the current state of technological developments in terms of the wireless data communications segment. The new concepts regarding the interconnection of all things through the new Internet of Things (IoT) technology were defined and presented, and the need to find the most reliable radio communication protocols with the lowest energy consumption was highlighted. From the analysis of several scientific papers and following the performance of various experimental tests, LoRa was chosen as the main communication system, due to the fact that it has a long range and has a low energy consumption, being particularly suitable for IoT networks.

The generic architecture of a LoRa network is composed of base nodes (the elements that monitor or control the given infrastructure), gateway devices that have the role of connecting the end-node devices (nodes) and the network server within which it is installed an application server. Communication between end-node devices and gateway devices is done using the LoRaWAN communication protocol. Communication between the gateway devices and the network server is done using a classic TCP/IP protocol. The chapter also presented some examples of programs implemented on different microcontrollers that allow communication between two or more points within a LoRa network. An IoT application was also presented that allows the acquisition of data regarding certain environmental parameters using LoRa and IoT specific concepts and technologies. After presenting the general framework of the research regarding the LoRa network and its integration into the current concepts of intelligent technologies, we moved on to solving a major objective of this doctoral thesis, namely the identification of possibilities for locating some elements of interest (in the case of the present research, of an electric vehicle) inside closed industrial premises where classic location technologies cannot be used.

After studying the specialized literature regarding the opportunities to use LoRa networks in order to create a localization algorithm in a closed space, several ways of solving this desideratum were identified, including triangulation, tri-lateralization and hyperbolic multilateralization. For the case of using the LoRa network as a general support for the localization system, the most suitable way to locate an object is to use hyperbolic multilateralization. Also using an interdependent relationship between the RSSI value (received signal strength indicator) and the distance from a central device (gateway), an algorithm was created to identify the position of a LoRa node, thus managing to create an integrated system for positioning and locating of an object, applicable in a closed industrial space. Even though the algorithm has only been tested and validated in certain particular cases managing to determine very accurately positions of a LoRa node only up to a distance of 21 meters from a central device, it represents a good achievement, being reliable, simple and easy to implement. A neural network was also designed and implemented in Matlab Simulink based on a data set of about 12000 values of the RSSI signal of a LoRa communication node depending on the distance to a certain fixed central point. After preparing the data by applying a Kautz approximation, it was loaded to develop an identifier that learns to determine the distance based on the RSSI value based on the measurements taken. The neural network thus achieved can calculate the position of a LoRa network node relative to a central device with a small error up to a distance of 100 meters.

Chapter 5 - Autonomous navigation

In this chapter, the main concepts regarding the field of autonomous vehicles were presented by synthesizing some specialized works and some remarks were also made regarding the ethical side of the general idea behind such a vehicle with reference to how much can we, as potential owners and users of such vehicles, allow them to make decisions and who is liable in the event of traffic accidents. The integration of specific sensors on the functional platform of the designed and realized electric vehicle was also presented. These sensors were chosen in such a way that they can retrieve the necessary data from the surrounding environment to be able to identify and map an area in order to create an autonomous driving algorithm applicable to a small electric vehicle. Thus, the family of LiDAR sensors has been identified with the help of which it is possible to create both systems for determining and monitoring the distance of the electric vehicle to certain fixed or mobile obstacles and a mapping of a closed perimeter of an industrial premises can be carried out in order to create a system of autonomous driving based on a simple, reliable and efficient algorithm. The beginning of the chapter presents the creation of a device for measuring the distance to certain obstacles using a specific LiDAR sensor.

After the development of the theoretical and applied notions in this field of research, a description was made of another type of LiDAR sensor, this time capable of mapping a certain perimeter of a premises established to be one of industrial use. After designing, modelling and implementing the mapping system using a RPLiDAR A2 LiDAR sensor capable of receiving data at a 360° angle, with a Raspberry PI development board and the open-source Robot Operating System application, the mapping of a campus building within the University of Petroșani and a detailed map of the construction elements of that perimeter was obtained. Then using the data regarding the location in a closed space obtained with the help of the LoRa communication system using an algorithm based on the received signal strength indicator (RSSI), an autonomous driving algorithm was developed and simulated in MatLab. The design, modelling and simulation of a simple, efficient, reliable and easy-to-implement autonomous navigation algorithm within the entire electric vehicle assembly made and presented in this PhD thesis represents a contribution to this research.

The algorithm is structured in 9 main stages of design and simulation as follows:

1) Using a LiDAR-type sensor to generate a map of the closed industrial area where the autonomous electric vehicle is intended to be used

2) Trajectory generation inside the generated map

3) Checking the position of the electric ATV in relation to the trajectory

4) Reading the position of the electric ATV using the LoRa tracking system

5) Orienting the ATV to the desired trajectory

6) Imposing the required position on the proposed trajectory

7) Determination of the steering angle of the ATV

8) Actuation of induction motor and servo motor

9) Obstacle detection

The results obtained, even if they are not perfect, satisfy to a very large extent the need to realize a simple autonomous navigation algorithm suitable to be implemented on an electric vehicle in a closed space.

The result, obtained following the realization of the research objective regarding the realization of the practical application within a closed space investigation system, is an integrated system on a functional platform of an electric ATV, featuring sensors and a LoRa communication and localization system as well as a system for mapping some closed industrial spaces used to create an autonomous driving algorithm, this intelligent autonomous electric vehicle can thus be used, for example, to prepare an industrial hall for access under health and safety conditions by personnel.

Chapter 6 – Conclusions, contributions and directions for further development

Conclusions

Concerns about the level of pollution around the world are increasing and every niche of every industry is trying as much as possible to find quick and effective solutions in an attempt to reduce pollution and achieve a sustainable development framework for future generations. The automotive industry has been, is, and will always be in a constant state of flux in terms of developing prototypes of eco-friendly vehicles that are then mass-produced. Today there is an increasingly high concern for the development of electric vehicles which, starting from the simple fact that they do not directly emit pollution, also have certain technical and technological developments that allow them to be included more and more in the new concepts regarding the Internet of Things (IoT), Smart Grid, Smart City and tend to become active elements in electricity supply networks as well, in the periods of high demand for electricity they can take the role of a prosumer-type element providing the energy accumulated in the batteries so that it can be recharged later in periods of low energy demand. Here are just a few of the areas of applicability of electric vehicles in the context of this new era. The development of the technology for the realization of electric vehicles, which today has reached the stage of maturity, allows major achievements at a much lower overall cost and together with the regulatory interventions applied by all the states of the world, there is an increase in the interest of buyers for this type of vehicle .

The doctoral thesis entitled ***Contributions regarding the use of electric vehicles in closed spaces*** presents the modelling, simulation and realization of a small electric vehicle suitable for driving on any type of terrain, driven by a motor controlled using the original approach of the theory of distributions and intended for a special case for use in closed industrial spaces.

Contributions

Regarding the part of the contributions made in the doctoral thesis, the contributions from the bibliographic research point of view and the analysis of the current state of the topic addressed are noteworthy.

• A detailed introduction to the research field of electric vehicles is made and a brief evolutionary history of the developments in this field is made based on the bibliography.

• The legislative framework in force is studied and summarized, especially for the area of Europe and the European Union, because in this part of the world electric vehicles are still not as widespread as in the United States of America. It highlights the fact that, although in the European area for many years electric vehicles did not represent a particular interest, against the background of recent legal regulations, an increase in their attractiveness is noted, due not least to the awareness of the major dangers regarding gases greenhouse effect produced by the vehicle industry with internal combustion engines.

• Based on scientific works from the specialized literature, the main technological developments in the electric vehicle industry in the last ten years and the current state of this field are presented.

• A major contribution from the point of view of bibliographic research is represented by the critical study of about 50 specialized works from which a synthesis could be made regarding the main characteristics of an electric vehicle and then of an autonomous electric vehicle.

• The concepts of electric vehicle and autonomous electric vehicle were defined and, starting from the identification of ethical issues regarding autonomous driving, a synthesis was made of the main achievements regarding driving models of an autonomous vehicle, planning methods of a route of this type of vehicle, methods of implementing the various algorithms used as well as methods of hardware implementation.

From the point of view of establishing the research objectives, several major contributions can be noted, starting from the establishment of the particularities of making an electric vehicle.
• Using the analysis of specialized works from the area of development and interest of the thesis, several general and specific objectives were formulated, designed and realized.
• Clear directions of action were then established to achieve each individual objective.
• The design of the drive and control part for an electric vehicle chosen to be built on the mechanical and functional platform of an ATV was carried out.
• A controller based on IGBTs and controlled on the basis of distribution theory for the induction motor was designed, modelled and realized.
• After the creation of the electric vehicle, the design of the communication system was carried out, which was assigned a dual role both as a system for interconnecting the vehicle with other vehicles or with the transport infrastructure and as a localization system in a closed industrial space where it is not possible using a classic localization system.
• A series of sensors were then identified that could be integrated into the functional structure of the electric vehicle equipped with a communication system and a localization system made in an original approach by using the LoRa communication protocol.
• The sensors identified and integrated in the electric ATV system with LoRa were used to identify some environmental recognition solutions, managing to create a LIDAR-type mapping solution.

From the point of view of theoretical research, multiple contributions can be noted that manage to define an electric vehicle with a communication and localization system based on LoRa and with a usable environment mapping system in order to create an autonomous vehicle intended for use especially in industrial closed spaces.
• A synthetic description of the evolution and operating principles of electric vehicles was made and a concrete analysis of the driving systems suitable for use in such a vehicle as well as in the case of an autonomous electric vehicle was carried out.
• Some conceptual delimitations were also made on the notions and terms used in relation to the new concepts of sustainable development that are related to the technologies used in the development of smart and sustainable electric vehicles.
• A synthesis of the results of fundamental and applied research in the field of development of the doctoral thesis regarding the main stages for the realization of an electric vehicle with intelligent type capabilities was carried out.
• After designing the entire drive system of the electric vehicle, a mathematical model of an induction motor and a simulation of its operation in Matlab Simulink was created.
• Based on the results of the simulations, it was possible to identify the electrical parameters necessary for a rewinding process of the induction motor to allow its supply at a maximum voltage of 110V.
• Using the induction motor simulation model, families of mechanical characteristics were drawn for different particular cases. Thus, was achieved the determination of the mechanical characteristics for different values of the supply voltage, mechanical characteristics for

different values of the stator resistance, mechanical characteristics for different values of the rotor resistance, mechanical characteristics for different values of the stator and rotor inductances as well as mechanical characteristics for different values of the supply voltage frequency.

• Modelling and simulation of the controller used to drive the induction motor was carried out in Matlab Simulink using the theory of distributions.

• Regarding the part of locating and positioning of the electric vehicle in a closed enclosure, two distance determination algorithms were designed and implemented according to the RSSI value of some LoRa nodes mounted on the functional structure of the vehicle, thus achieving a reliable and easy to implement system.

• An important contribution regarding the realization of this positioning and localization system inside a closed enclosure, is represented by the realization of a machine learning algorithm implemented with the help of a neural network realized and validated in Matlab Simulink.

• Another contribution made within this doctoral thesis is related to the design, modelling and simulation of an autonomous navigation algorithm, simulated and validated in Matlab Simulink, as well as the development of mathematical support and Matlab programs for the generation of movement trajectories for the electric vehicle.

The objectives proposed to be solved within this doctoral thesis were achieved and fully implemented by obtaining an electric vehicle driven with the help of a controller made using a different approach compared to existing models, with LoRa communication and localization system being at the same time able to identify and map certain closed industrial premises to be able to obtain the data necessary to use an autonomous navigation algorithm designed and made. Testing in laboratory conditions highlighted the reliability of the entire system and thus validated the electric vehicle. For the electric drive part, the implementation of the LoRa communication and localization system and for the identification of original ways to recover part of the electricity consumed in order to increase the autonomy of the electric vehicle, the OSIM invention patent application was registered with the number A00201/28.03.2019 .

DIRECTIONS FOR FURTHER DEVELOPMENT

Regarding future research directions, two main proposals can be defined.

• The first proposal for future development refers to the implementation in the existing hardware structure of the realized electric vehicle of a servomotor-type execution element as well as specific sensors with the help of which an autonomous electric vehicle can be obtained that can run in conditions of complete safety in any type of premises with the help of localization, positioning and autonomous navigation algorithms specially made for this purpose.

• The second major proposal for future development is related to concepts related to sustainability and environmental protection because this vehicle was made mostly of recycled components and parts but still does not have a renewable energy supply system, so that the vehicle is truly ecological. In a different vein and thinking on a macro scale, it is proposed to build an intelligent system in the city of Petroșani consisting of sources and equipment for the production of electricity from renewable sources and electric vehicles that will widely integrate the concept of V2G (vehicle-to-grid). Although the wind energy potential is relatively good due to the geographical location of the municipality of Petroșani, due to the high costs regarding the realization of wind turbine installations, a system of photovoltaic panels spread over the roofs of buildings in the city is proposed. After carrying out some simulations, it was found that the need for electricity just to power all the electric vehicles needed for a percentage of 70% of the population of the city of Petroșani is only 17.72% of the production potential from photovoltaic sources only. So, it can be said that the whole concept is sustainable and can be used. Regarding the vehicle-to-grid concept, the creation of smart personal electric vehicle charging stations can help to balance the electricity supply grid by the simple fact that a personal electric vehicle when not in use can be connected to the network providing the energy stored in the batteries during periods of high consumption thus becoming a prosumer type element to be charged during periods of low energy consumption.

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