Trends in AI based Automotive Industry using Patent Analysis

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***Abstract* — Until a few years ago, the key factor that led the car buyers were engines under the hood, now it's their technology. These trends, introduced by a younger generation of drivers, are an increasingly important marketing factor. Thus, the choice of vehicles, access to information, comfort, convenience and mobility significantly changes the image of the industry. These solutions require the use of artificial intelligence (AI) in cars. The aim of this paper is to present the results of the research related to analysis of the development trend of artificial intelligence in the automotive industry. Our analysis shows the overall development trend for the considered patent portfolio related to the development and application of AI in the automotive industry.**

***Keywords* — Artificial intelligence, automotive, patent analysis, technology analysis.**

I. Introduction

THE rapid development of information-communication and robotics technologies has a strong impact on the automotive industry. Vehicles are becoming more technologically advanced, where driver's participation in control of the vehicle is reduced or completely omitted. Consequently, safety requirements are significantly increased. All this leads to the growing of a number of different sensors built in the vehicle, so the vehicles become machines for collecting, processing, and displaying data in real time. Due to the increasing amount of data and requests to speed-up it's processing, there is a need to find effective methods to process them. The best way to do that imposes the application of artificial intelligence (AI).

Development of technologies is followed in the increase of acompanied amount of the filed patent applications. It is well known that patents may serve as a excellent source for researching future trends and technological development trends. Patent analysis uses statistical methods to analyze, process, and visualize large amount of structured and unstructured information retrieved from patent specifications. Data obtained by statistical analysis of patent documents can give an insight into the market orientation of the industry branch [1].

Patent analysis can be applied to different industry sectors with more or less success. The analytical method, as well as data used for analysis, can be different. In addition to the above mentioned differences, analysis may be geographically limited [2] or restricted at a specific observed time period [3].

The goal of this paper is to present the research results of the patent dataset in the field of artificial intelligence application in the automotive industry. This paper will show the patent application trends, most active countries and companies, and which are the most attractive technologies applied.

The paper was organized through sections to present the research results of AI trends in the automotive industry obtained by patent analysis. The first section explains the methodology used during the research process. The second section presents the analysis of the obtained results. At the end, there will be a discussion about the results obtained and the conclusion of this research paper.

II. Methodology and Data Collection

The subject of the paper is the patent portfolio that consists of patents in the domain of artificial intelligence in the automotive industry sector. The portfolio is titled Artificial Intelligence based Automotive Technologies (AIauto) and consists of 161 documents.

The AIauto patent portfolio is generated by browsing publicly available patent search engines. Firstly, two sets of keywords were applied on abstract of patents. Each selected abstract needed to have at least one term from the keywords set. The first set of keywords contains terms related to the artificial intelligence algorithms and methods (decision trees, neural networks, machine learning, etc.), while the second group of keywords cover automotive technology (e.g. vehicle, autonomous driving, etc.). Besides, we have implemented an additional keyword set that consists of terms such as: airplane, ship, drone, or similar in order to exclude patents that mentioned these subjects. Finally, we filtered out all inactive patents, and as result we created the AIauto patent portfolio with 161 granted patents and pending patent applications.

The generated AIauto patent portfolio is further classified according to the following criteria: Applied Artificial Intelligence (AI) techniques, and domain of application. Both classifications are based on an engineer specialist review of the most frequent terms used in the patents' abstracts. According to AI techniques classification, all patents are divided into three classes:

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conventional machine learning, deep learning and fuzzy systems. Within some of these groups there are other sub-groups that were created.

Another classification of the portfolio according to the domain of application is presented with four classes: 1) Image Classification; 2) Routing and Navigation; 3) HMI/MMI systems (Human-Machine interfaces / Machine-Machine interfaces), and 4) Monitoring and Control (systems relating to the control and monitoring of safety systems, the engine and power supply of the vehicle).

Analysis of the AIauto patent portfolio consists of evaluation of the following characteristics:

- Top assignees and application trends;
- Most frequently used IPC subclass;
- Classes of AI techniques employed;
- Top companies involvement into the application classes;
- Review of the most cited patents;
- Technological similarity visualization of the selected companies.

Except the last one, all evaluation steps use simple statistical procedures. However, preparation of the visualization of the technological similarity requires a more complex procedure. The algorithm for evaluation of technological similarity between specific companies uses the Cooperative Patent Classification (CPC) codes. The CPC is a patent classification system which represents a more detailed version of the International Patent Classification, and it is jointly developed by the European Patent Office and the United States Patent and Trademark Office. In the first step of the algorithm, portfolio's patents are grouped by the assignee name criteria, and all IPC codes from the patents subsets are extracted into separate lists. Generated IPC lists that characterize patents belonging to the same companies are processed using the Term Frequency-Inverse Document Frequency (TF-IDF) algorithm. TF-IDF is a statistical method for determining the importance of words within a document, which belongs to a larger set of documents [4]. The output of the applied TF-IDF algorithm is a matrix whose rows represent relative frequency appearance of CPC codes in the patents of each company. In order to visualize relations between companies in the technology space based on CPC codes, reduction of the TF-IDF output matrix is conducted using the Multidimensional scaling statistical procedure (MDS) [5].

III. Analysis and Results

In this part of the paper we compare the results obtained by studying the previously prepared patent portfolio. Results of the research will be displayed through different graphics and statistical data. The most significant characteristics of this patent portfolio will be presented.

A. Top Assignee

The research has shown that the development of artificial intelligence in the automotive industry includes a large number of companies. Due to a clearer and more precise presentation of which company owns how many patents in its portfolio, acquisitions of a subsidiary by the parent company were taken into account.

The obtained results for this patent portfolio of 161 patents show that the top 10 companies in the field of AI in automotive possesses 84% of all patents in this field, while other companies have only 16% of patents. This can be seen in the following graphic (Fig. 1), where leading companies are shown by the number of patents in the portfolio.

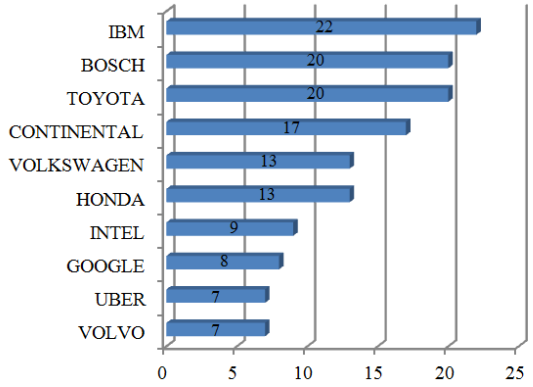

Fig. 1. Top patent assignees in the AIauto portfolio

It can also be noted that among the top 10 leading companies, they are not the only companies that develop the automotive industry as their primary activity. Even more, it can be noticed that the two leading companies are not primarily automotive-oriented. What is common to all these companies is that they are all related to the development of electronic components and the IT industry in general.

B. Patent applications trend

Fig. 2 represents the patent applications trend in respect to its assignees for this portfolio. There is a significant increase in applications filed in the last year, which indicates the direction in which the automotive industry is going. It may also be noted that the companies such as IBM and Intel take priority in development and research, whose primary field of work is not related to automotive industry, but the development of computer hardware and software. On Fig. 2, a patent application trend for the period of five years is shown – from 2012 to 2016, where year 2017 has not been considered, since its data is still incomplete.

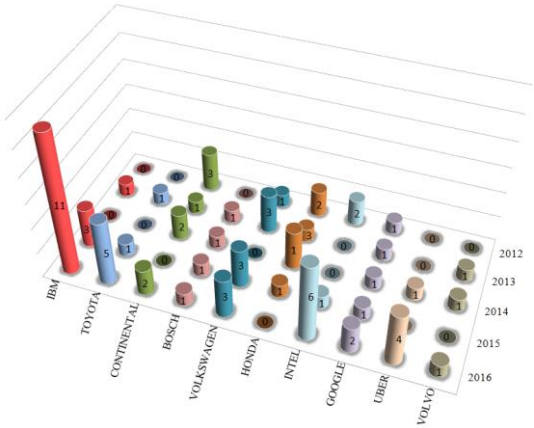

Fig. 2. Application trend of the top assignees in the AIauto portfolio

A. *IPC subclasses*

On Fig. 3, the trend of IPC subclasses for the AIauto portfolio, for the period of 5 years – from 2012 to 2016, is shown. It also shows top 5 dominant IPC subclass codes for the AIauto portfolio, while Table 1 shows the definition of these codes and how many times these codes are repeated in the AIauto portfolio.

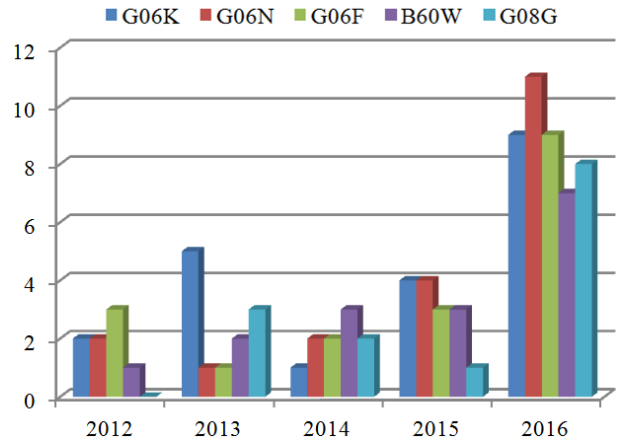

Fig. 3. Trend of IPC subclasses in the AIauto portfolio

TABLE 1: EXPLANATION OF THE TOP IPC SUBCLASSES

IPCs subclass	Description	Total
G06K	Recognition of data, presentation of data, record carriers, handling record carriers	21
G06N	Computer systems based on specific computational models	20
G06F	Electric digital data processing	18
B60W	Conjoint control of vehicle sub-units of different type or different function, control systems specifically adapted for hybrid vehicles, etc.	16
G08G	Traffic control systems	14

It can be concluded that the dominant IPC subclasses describe the operation of computers, calculation of data, in combination with the IPCs that describe vehicles in general.

From this chart it can be noted that the trend of development in recent years is turning toward systems for processing and data recognition, systems that have the ability to recognize certain patterns, and perform certain calculations for the purpose of self-learning in vehicles. These systems are commonly used for traffic control, control of vehicle position, automatic piloting, navigation, etc. The highest increase was the application of IPC subclass G08G, whose application in the last year has been increased eight times, and subclass G06F with an increase of three times.

B. *Implemented AI techniques*

Also, patents from this patent portfolio are classified according to the AI techniques or methods that they employed. The techniques are divided into three groups: conventional machine learning techniques, deep learning, and fuzzy logic techniques. Thereby, we have to take into account that some patents apply more than one technique, which will result in the sum of the percentages in the final application of various techniques in patent, reaching a higher percentage of 100.

For the observed patent portfolio of 161 patents, the results are as follows: The most common technique is the conventional machine learning, used in 92% of all patents. This information is not surprising considering that it includes numerous and different approaches. The next group of techniques is deep learning, which is used in 13% of the total number of patents, and the third, least-represented technique is fuzzy logic with 4% of patents. In a more detail view of the conventional machine learning techniques, the most common are neural networks with 35% of patents, while 32% of patents is machine learning in general, that is, those patents haven't had a specific ML technique defined. The next most commonly used conventional ML technique is support vector machine (SVM) with 9% of patents, and decision trees with 8% of all patents from this group. Among the deep learning techniques, the most commonly used techniques are convolutional neural networks with 43% patents, and recurrent neural networks with 24% patents, while all other techniques populate the remaining 33% of this group.

TABLE 2: OVERVIEW OF AI TECHNIQUES PRESENT IN THE AIAUTO

Conventional machine learning 92%	**Deep learning 13%**	**Fuzzy systems 4%**
Neural network: 35%	Convolutional neural networks: 43%	Fuzzy logic: 83%
ML in general: 32%	Recurrent neural networks: 24%	Other sub-techniques: 17%
Support vector machine: 9%	Other sub-techniques: 33%	
Decision tree: 8%		
Other sub-techniques: 15%		

C. *Patent application areas*

Looking at the relationship between the technical application of patents and a group of techniques used for the realization of AI, it can be noted that all four groups, according to the purpose of the patents, have the same relation to techniques used for the realization of AI. In all four groups, the most commonly used technique is conventional machine learning, i.e. artificial neural networks and machine learning techniques in general. The remaining techniques constitute a minor part of the total number of patents.

We selected top 6 leading companies, since they constitute 65% of the total number of patents from the AIauto patent portfolio. In relation to the techniques applied to AI, it was noticed that almost all top 6 leading companies dominantly use conventional machine learning techniques, either machine learning in general or neural networks. This is true for all companies except for Toyota, which has a patent portfolio with a significant number of patents in which they use deep learning and fuzzy logic techniques.

By comparing the relationship between the top leading companies, and with the previously mentioned technical application of the patents, it is noted that most patents are related to the Monitoring and control functional group, i.e. systems relating to the control and monitoring of safety systems and operation of the engine and power supply system of the vehicle. These results were expected, given that the fourth functional group is much wider in function

compared to other three groups. However, with Volkswagen and Honda this difference is not as high, and there is uniformity in the representation of patents by functional groups.

TABLE 3: INVOLVEMENT OF SELECTED COMPANIES IN THE APPLICATION GROUPS

#	Company	Image detection and classification	Routing and navigation	HMI/MMI systems	Monitoring and control
1	IBM	2	4	6	10
2	BOSCH	3	2	4	11
3	TOYOTA	4	4	1	11
4	Continental	2	2	3	10
5	Volkswagen	3	3	2	5
6	Honda	3	3	3	4

TABLE 4: TOP CITED PATENTS FROM THE AIAUTO PORTFOLIO

Publication Number	Assignee Name	Application groups	AI technology	Application Date	Cited by	citations per year
US6301440	IBM	Image Classification	neural networks	2000-04-13	414	23
US6970602	IBM	HMI/MMI systems	decision tree	1999-10-06	224	11,8
US8634980	Google	Routing and Navigation	machine learning	2011-09-29	74	10,6
US6333703	IBM	HMI/MMI systems	neural networks, Bayesian network	2000-10-04	108	6
US8098889	Continental	Image Classification	support vector machine	2008-01-15	38	3,8
US8190318	Honda	Monitoring and Control	neural network	2009-04-08	32	3,6
US7526120	Canesta	HMI/MMI systems	neural network, SVM, nearest neighbor classifier, LDA	2003-09-11	46	3,1

Applicability of a patent refers to the citation of a patent. When a patent is more cited, its applicability is greater. However, for the citation of a patent, the absolute value of the number of citations is not taken, but the average number of citations per year in relation to the year of application for the given patent. A patent citation can distinguish those patents that are influential, dominant technology, or to point out the most important companies. Table 4 shows patents that have the highest average number of citations per year. All patents which have $\mu + \sigma \geq 3{,}07$ are listed, where σ is the standard deviation with a value 2,47 and μ is the mean value of the number of citations of the patent portfolio with a value of 0,6. The first three patents in Table 4 satisfy the condition $\mu + 3\sigma$, therefore we treat them as an outliers in this distribution. Almost all assigned companies, except two, are companies that are IT-oriented and their primary activity is not the automotive industry, but the development of software and computer hardware. As it can be seen from this table, most patents belong to the group of HMI/MMI systems. By reviewing this group of seven patents, it has been found that most of them are engaged in collection, processing, transmission and presentation of different data. Most of these patents are written in such a way that they are not intended exclusively for use in automotive, and that it is only one of the possible uses of these patents. This supports the fact that almost all companies on this list are primarily IT-oriented, rather than on the development of vehicles. Therefore, the scope of these companies' research is far wider than automotive, and application of these patents covers more areas of development.

D. Evaluation of the technological similarity between specific companies

Fig. 4 represents results of the technological similarities' evaluation between selected companies, using the Cooperative Patent Classification (CPC) codes. We selected top 6 leading companies from AIauto portfolio, since they constitute 65% of the total number of patents from this portfolio. The diameter of each circle is proportional to the number of patents that the company has in this portfolio, and the distance between the circles represents the technological similarity/difference between the companies. For example, if we look at Honda, we will see that it is technologically similar to Toyota and Volkswagen, but diametrically different from BOSCH or IBM. Volkswagen has the same similarity with almost every company, except IBM.

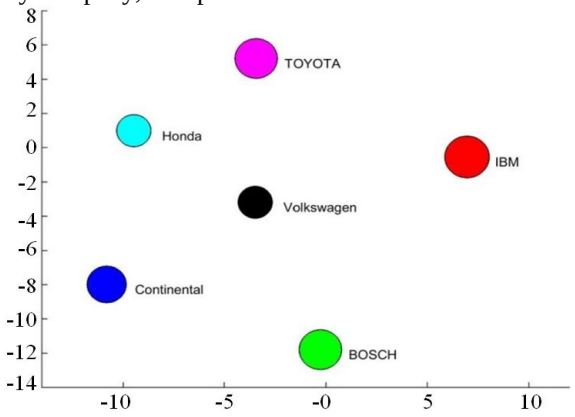

Fig. 4. Technology similarity of the top OEM companies

IV. CONCLUSION

From this paper it can be concluded that application of AI in automotive has already been largely in progress and will occupy an important role over time. Also, the automotive market is becoming more open in terms of presence other companies that are not primarily automotive oriented. The application of AI has opened the door of the automotive industry primarily to the companies from the IT sector, and they have largely accepted it. This paper gives an insight into the directions of development of this relatively new branch of the automotive industry and can serve as a good basis for further research in the field of automotive industry monitoring.

ACKNOWLEDGMENTS

This work was partially supported by the Ministry of Education, Science and Technology Development of the Republic of Serbia under the Grant number III44009-6.

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