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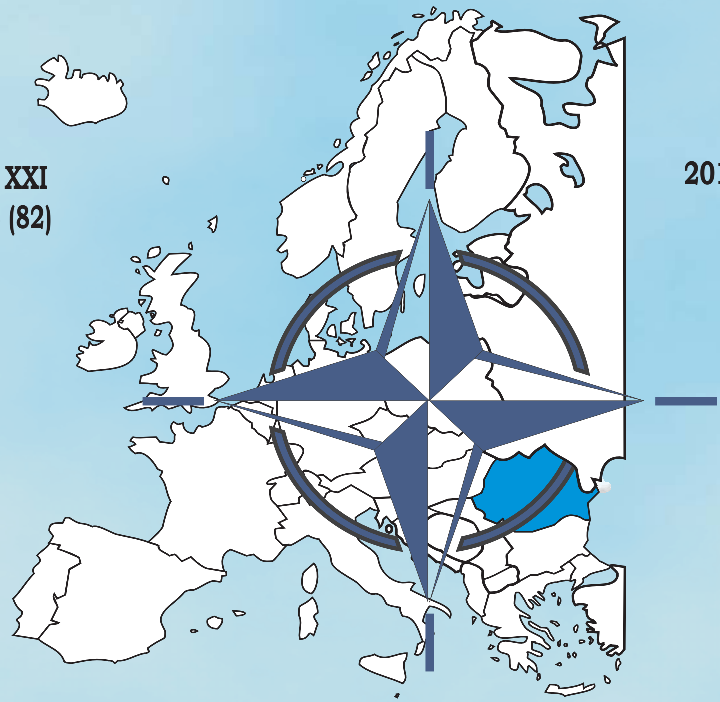

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DIAGNOSTICS OF THE BATTERIES TECHNICAL STATUS USING SVM METHOD

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ABSTRACT
In this paper authors will investigate a new description of the parameter tolerances used for the batteries of an UGV. The article will highlight battery data analyzed by a Support Vector Machine and simple practical data without any analysis. The authors checked the data with Fuzzy logic and they find the best operation parameters where the batteries can work with appropriate level of safety. The authors describe the future works of the operational parameter analysis with the Internet of Things.

KEYWORDS: autonomous vehicle, UGV, SVM, classification, fuzzy logic

1. Introduction

Nowadays electric vehicles being mainly autonomous ones try to enhance bigger ranges. It is an important issue in daily traffic, in industrial life or in military applications. Research results show that the biggest potentials are in lithium polymer batteries. These kinds of batteries are widely used in electric vehicles and robot applications like UGVs or UAVs.

Thanks to the researchers and manufacturers the limits of the physical properties of the batteries nowadays have a bigger range than even before. Engineers try to develop more and more optimal charging and/or discharging strategies. In some case it is not enough to enhance battery technical properties.

In different applications users have to use the vehicles or robots for longer periods, it means that the robots' maintenance strategy can miss the optimal time period. In case of military applications the mission times can change during the missions, in these cases the users have to use a new domestic strategy or they have to use the batteries in a wider range.

The authors found a difference between the theoretical and empirical battery data. In real life batteries can be used in a wider range than it is forecasted by manufacturers.

During the research work the authors have two important issues being investigated. The first is to determine the new and wider operating conditions for the batteries. The second is to find safety operating conditions for the batteries without any overheating or any other problems like explosion. The article contains 3 chapters. The first is the introduction, the second chapter gives a description of the related works, the third describes the new range of the batteries.

2. Preliminaries and Related Works

Verena Klass (2015) et al. write about the battery health estimation in electric vehicles. Her doctoral work presents the importance of electric vehicle batteries. Verena Klass writes about some of the main properties of electric vehicles: electric vehicles have to be safe, reliable and cost effective. Her works describe the nowadays most important energy source which is the lithium ion battery. She states that the batteries will become cost-effective in the future. She mentions voltage losses in the batteries. She analyzed her measuring results with a support vector machine. Her project was sponsored by Scania, Volvo and the Swedish Hybrid Vehicle Centre (Klass, 2015; Klass, Behm & Lindbergh, 2015).

Kim (2012) describes the importance of real time monitoring of a lithium ion battery. The developed battery model can be used on battery power management for optimization and prolong the operating time of battery cells in real time. In her future work the author would like to check other effects, like temperature or aging effect, on the batteries (Kim, 2012).

The voltage-based estimation methods can produce an amount of errors when applied in some batteries (e.g.: LiFePO4). (He, Willard, Chen & Pecht, 2013) contains a description of the state of charge estimation for electric vehicles with unscented Kalman filtering (He, Willard, Chen & Pecht, 2013).

Rahman & Anwar, (2015) presents an approach in detecting faults in electric vehicle batteries. The author used this multiple model adaptive estimation (MMAE) technique of the electrochemical model of Li-Ion cells. The authors work with the aging, overcharge and over-discharge like a battery fault condition. The authors use the MMAE algorithm to detect faults in the system. They mention the Li-Ion batteries as a main energy source of the future. In their conclusion the authors find a solution to use MMAE in real time.

Allaoua & Laoufi, (2013) describes a sliding mode fuzzy control and SVM base method for electric vehicles' propulsion system.

Hanmin Sheng and Jian Xiao (2015) work on a SOC of lithium iron phospate battery pack charging strategy system with machine learning. The authors proposed a nonlinear correlation method in their study. With this method they solved a fuzzy rule extraction problem.

Sanna Pöyhönen (2002) uses the support vector machine in fault diagnostics. The author use the SVM method in an electric motor's fault diagnostics. The study describes the importance of the Artificial Intelligence (AI) based analyses and the importance of the lead downtimes in production plants.

Robert Szabolcsi's book (2011) and the online support websites for MATLAB (MathWorks, 1994-2016) help in the MATLAB simulations, Laszlo Pokoradi's (2008) book was helpful in fuzzy logic.

3. Batteries' Voltage Analysis

3.1. Support Vector Machine Classification

Nowadays the Support Vector Machine (SVM) method is very popular for data analysis. This method can make an optimal hyperplane separate data (Fazekas, 2013; SVM Tutorial, 2016; Owen, 2010; Xie, 2016).

The theoretical and practical data show different results. The practical data make a better number for the daily usage of the batteries. But it is important to know the most important properties of the Lithium-ion batteries. These kinds of batteries are very sensitive to overcharging or low discharging procedures (Pokorádi & Menyhárt, 2016).

These properties can lead to overheating and the batteries can blow up, but the practical data show the batteries can abide a few overcharging and the users can use it with new allowable limits. The question is: what is the limit batteries can work with a good efficiency and the with appropriate safety level? (Pokorádi & Menyhárt, 2016)

Table no. 1 contains the maximum prescribed voltage and the practical test voltage results.

Table no. 1

Practical and prescribed values

Measurements	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.
Practical voltage (upper)	4.392	4.2	4.39	4.41	4.438	4.41	4.378	4.42	4.4	4.397
Prescribed max. voltage (upper)	4.2									
Practical voltage (lower)	2.62	2.65	2.73	2.9	3	3.15	3.2	3.19	3.18	3.2
Practical voltage (lower)	3.2									

Table no. 1 shows the batteries' voltage data. During the investigation the SVM method was used to find the optimal hyperplane to the new upper voltage limit of the batteries. Figure no. 1 shows the prescribed (blue) and the practical range (orange).

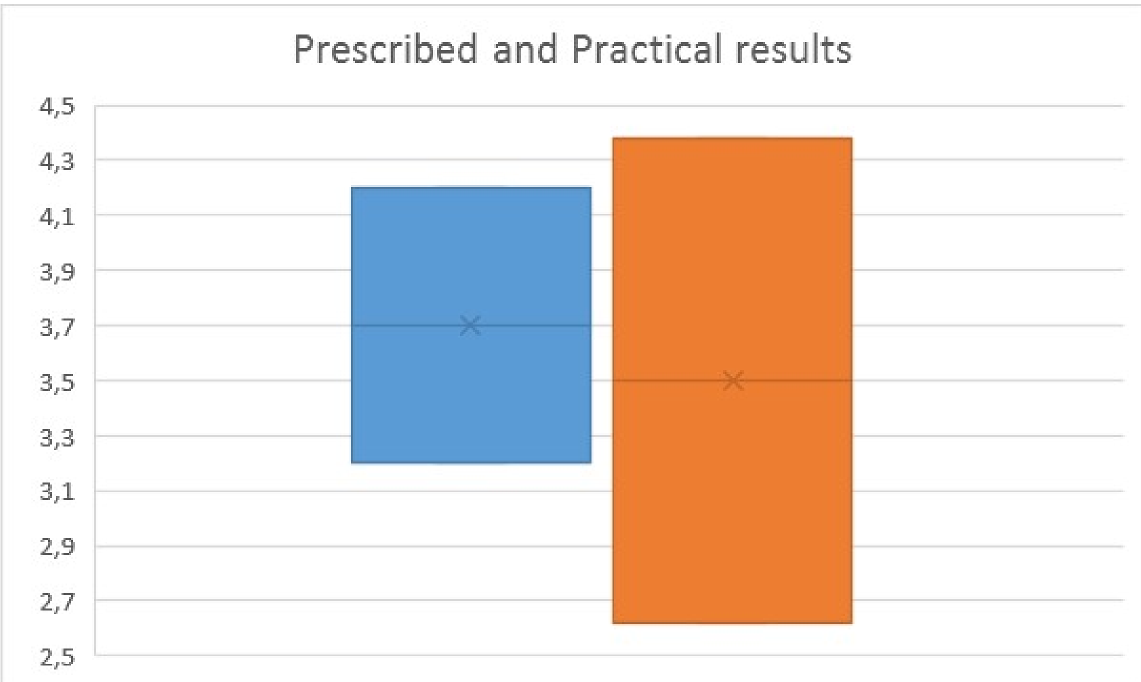

Figure no. 1 The prescribed and empirical ranges of voltages of the batteries

Figure no. 2, left, shows the new upper limits of the batteries, Figure no. 2, right shows the lower limits of the batteries' voltages. The test results show that in the upper limits the batteries can work with more ~4,23 % in the lower case ~18,13 %. The MATLAB calculates the margins and marks the support vectors on the margins. The support vectors define the new limits of the batteries voltage (MathWorks, 1994-2016; Fazekas, 2013).

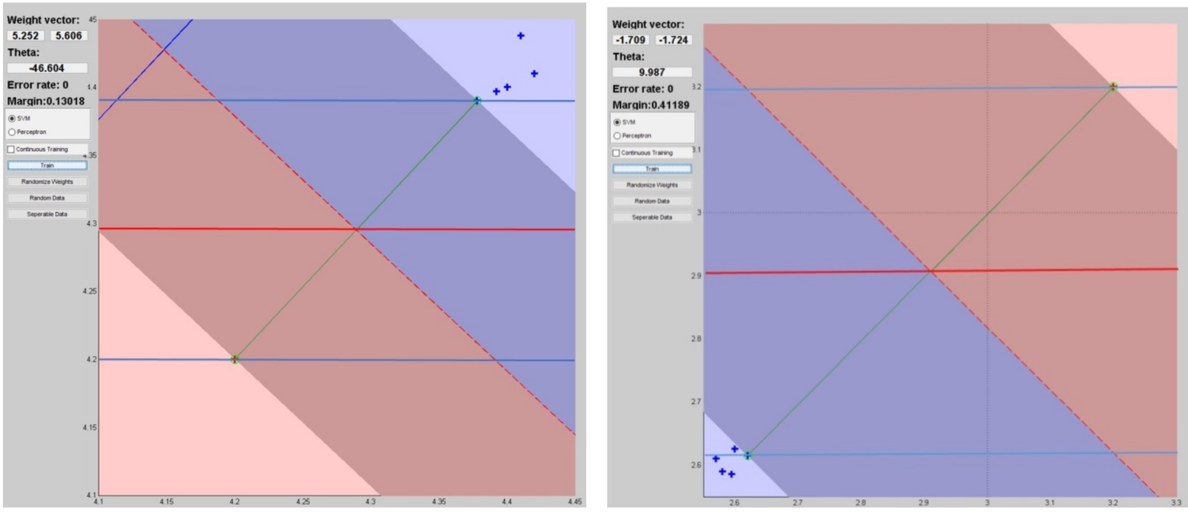

Figure no. 2 The SVM margins: left: upper; right: lower

3.2. Data Evaluation Using Fuzzy Logic

In the practice we can find variance in the measured results (SVM Tutorial, 2016; MathWorks, 1994-2016). The authors used fuzzy logic to find a precise result of the batteries where they can work safely. Measurement data are tabulated in Table no. 2 (Pokorádi & Menyhárt, 2016).

Table no. 2

Batteries Dataset

		Empirical value
V_{maxSVM}[%]	Min	100.00 %
	Max	104.06 %
	Average	101,48 %
	Median	101,21 %
V_{minSVM} [%]	Min	76.19 %
	Max	62.38 %
	Average	68.11 %
	Median	70.23 %
V_{max} [%]	Min	100.00 %
	Max	105.67 %
	Average	104.85 %
	Median	104.76 %
V_{min} [%]	Min	76.19 %
	Max	61.19 %
	Average	61.90 %
	Median	61.90 %

The Fuzzy membership function of parameter tolerances is given by the general form of (Pokorádi, 2008; Pokorádi & Menyhárt, 2016):

$$\mu_i(x) = \frac{1}{1+e^{a_i(b_i-x)}} \quad (1)$$

Table no. 3 contains the coefficients of the Fuzzy membership function defined by equation (1) (Pokorádi & Menyhárt, 2016).

Table no. 3

Calculated Coefficients

Parameter (i)	a_i	b_i
V_{maxSVM}	2.46	101.274
V_{minSVM}	1.466	69.12
V_{max}	2.5	102.835
V_{min}	1.5	68.690

The membership functions calculated using coefficients tabulated in Table no. 3 are presented in Figure no. 3 (Pokorádi & Menyhárt, 2016).

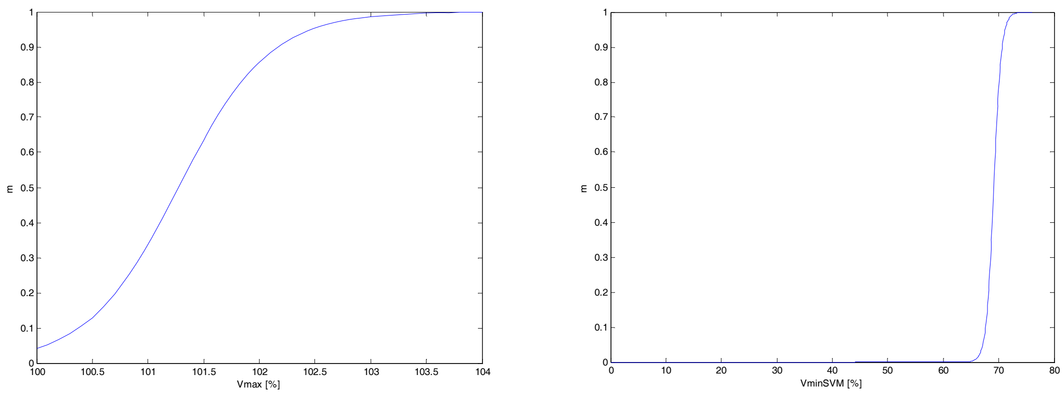

Figure no. 3 The Fuzzy membership function. Left: V_{maxSVM}. Right: V_{minSVM}.

3.3. Results of the New Acceptable Parameter Tolerances

The battery management system (BMS) checks two parameters of the voltage. These are maximum and the minimum parameters. The BMS has to make an intervention when the batteries reach either of these two limits. The system has two ways in this case. It has to start the charge or it has to stop the charge (Pokorádi & Menyhárt, 2016).

We have to use OR logical connection between the conditions. The logical rule's truth value surface is (Pokorádi & Menyhárt, 2016):

$$\boldsymbol{\mu(V_{maxSVM}; V_{max}) = MAX\left(\frac{1}{1+e^{a_{V_{maxSVM}}\left(b_{V_{maxSVM}}-x\right)}}; \frac{1}{1+e^{a_{V_{max}}\left(b_{V_{max}}-x\right)}}\right)} \quad (2)$$

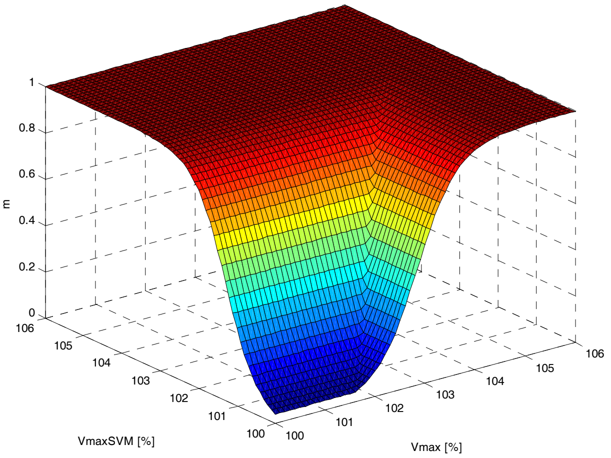

Figure no. 4 The Fuzzy membership function of V_{maxSVM}.

If the voltage is low, the BMS has to start the charging process. In this case we have to follow OR logical rules again. The truth value surface is (Pokorádi & Menyhárt, 2016):

$$\boldsymbol{\mu}(\boldsymbol{V_{minSVM}}; \boldsymbol{V_{min}}) = \boldsymbol{MAX}\left(\frac{1}{1+e^{a_{V_{minSVM}}\left(b_{V_{minSVM}}-x\right)}}; \frac{1}{1+e^{a_{V_{min}}\left(b_{V_{min}}-x\right)}}\right) \quad (3)$$

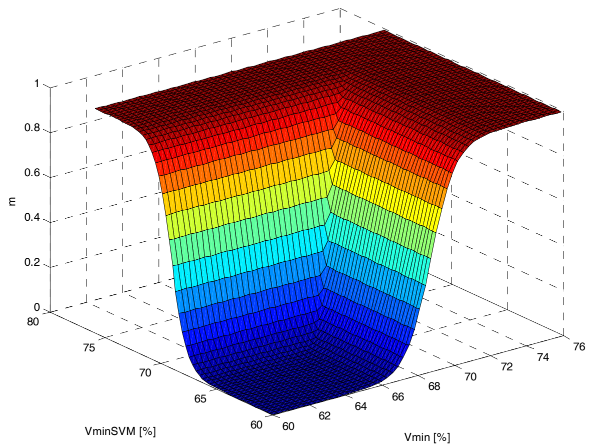

Figure no. 5 The Fuzzy membership function of V_{minSVM}.

The practical experience shows that we have determined the truth values between 0.7-0.8. It means that the batteries' charging process and/or immersion can be dangerous above 0.8. Table no. 4 and Table no. 5 contain the data for 0.7 and 0.8. (Pokorádi & Menyhárt, 2016)

Table no. 4

V_{maxSVM} and V_{max} Truth values

V_{maxSVM}		V_{max}	
μ=0.7	μ=0.8	μ=0.7	μ=0.8
101.65%	101.85%	103.2 %	103.4%

Table no. 5

V_{minSVM} and V_{min} Truth values

V_{minSVM}		V_{min}	
μ=0.7	μ=0.8	μ=0.7	μ=0.8
69.7%	70.1%	69.26%	69.62%

4. Conclusions

The diagrams and the tables describe the differences between the theoretical and empirical data. The results show some difference between the data. The SVM method calculates unsparing results. Thanks to this difference between the data, the batteries can work with a better safety. During the investigation the researchers can calculate with the data.

The authors describe the theoretical and practical data in tables and illustrate the values in 2D and 3D format. The authors define an optimal operation parameter where the batteries can work with appropriate level of safety.

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