A Wind Power Potential Study Applying Three-Parameter Weibull Distribution and Evolutionary Algorithms

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**Abstract.** An intelligent linear and nonlinear control of renewable resources leads to a study on estimating the minimum power produced by a portable wind turbine in a military medical camp, by modelling the wind speed distribution and determining the energy production at a minimum wind speed. Thus, the Weibull distribution with three parameters was used in the sense of nonlinear control of the probabilistic wind speed distribution, depending on location. Using the Maximum Likelihood Method implemented in Python and the minimum wind speed, each value in the reference range of the shape parameter was assigned corresponding values of the scale parameter. By applying the Grammatical Evolution algorithm, which implies a context-free grammar, the most reliable form of the scale parameter was obtained. May be interesting a graphic simulation for a mobile platform using one of the game engines, which should evaluate the wind turbine project’s reliability.

**Keywords**: *Weibull Distribution, Grammatical Evolution, Wind Power Potential, Maximum Likelihood Method.*

# INTRODUCTION

In the present research, it is proposed a wind speed modeling (WSM) study based on Three - Parameter Weibull Distribution (WD3) and Grammatical Evolution (GE), both being reasoned as a non-linear control geared toward a self-conscious problem-solving algorithm [1-4].

WD3 is at the base of WSM, the various values of shape parameter being thought as particular climates, and the location parameter being considered as the minimum wind speed (MWS) of modelling array [1], [2]. By means of Maximum Likelihood Method (MLM), together with the algorithm in Python, the estimated form of the scale parameter is achieved [3]. As a result, the WSM is obtained. Not only wind speed (WS), and are variable, but also varies with the array of the measured WS.

The similarity of WSM and initial data proves that the algorithm is entirely ready to be automatized. Hence, Genetic Programming (GP) is applied along with GE formalisms, considering some environmental variables [4], [5]. GP and GE are perfectly fit for the situations when operations with big data are supposed and, unfortunately, there is no direct path for obtaining the result. These modern algorithms should provide the best estimated WSM for the chosen human settlement.

# methodology

## Biomimicry in Programming

### Genetic Algorithm and Genetic Programming

The Genetic Algorithm (GA) is a base technique of Biologically Inspired Algorithms (BIA’s). In the book written by O’Neil and Brabazon in 2006, they have structured all BIA’s as in the Fig. 1. In addition, there are marked programming formalities applied in this research [4], [6-9].

GP has two basic differences in comparison with GA. Instead of evolving binary strings, which represent an indirect coding of a potential solution, in GP the search is applied directly to the solution, in this case, solutions being programs. In the GP formalism, pronounced by John Koza, these programs have the form of an "S-expression", which represents a syntax scheme. Fig. 2 represents his vision of coding a row.

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| Figure 1. Tree type scheme of BIA's [4] | , x, y are predefined constants    Figure 2. “S-expression” example (left), and associated syntax tree (right) [4] |

In GP, it is recognized that the length of the solution cannot be known from the beginning, so the number of genes (codons) must also have evolved itself [10]. Each individual, after the initialization of the first population in GP undergoes a certain "lifecycle" which consists of processes similar to those in nature.

Lifecycle is presented in Fig. 3 and represents these main processes: 1. selection, which is a process of choosing the most suitable individuals, according to the "fitness" function, which simulates environment in case of a program; 2. crossover (crossing over) is the procedure of recombining the parents' genes; 3. mutation is made to avoid cases when the population "falls" in a local minimum. It represents a small random change in the values of several parental genes; 4. reproduction is a process which creates a new generation based on all the steps taken before. Once it has been created, the cycle repeats until a solution is found or the limit of generations is reached [4], [11], [12].

### Grammatical Evolution

GE is a formalism that makes a supplementation to the original GP, basing on the idea of adding a grammar. This is a language proposed by John Backus and Peter Naur as a formal notation to describe the grammar of any other language.

Among the advantages of applying GE, we can mention: 1. application of a “mapping” algorithm for transforming a “genotypic” binary or integer string, produced by the GP into a “phenotypic” output program. In other words, the transition from tree-type syntax (GP) to linear-type syntax is performed; 2. GE has a modular architecture as presented in Fig. 4. This provides more space for optimizations; 3. “output” of a GE is data written in arbitrary languages programmed in the BNF [5], [13], [14].

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| Figure 3. An individual's life cycle in GP [13] | Figure 4. Representation of the modularity of the GE design [5] |

A BNF grammar represents a tuple containing 4 components shown in Fig. 5: 1. “N” are non-terminal symbols. These expressions will map into T; 2. “T” are terminal symbols. These symbols will enter in the output; 3. “P” are production rules for “N” and “T”. A remarkable example is shown in Fig. 6; 4. “S” is the start expression. Mandatory a member of “N”.

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| Figure 5. Representation of the grammar in the example “Boolean Expression” (P is omitted) | Figure 6. BNF grammar describing BNF rules [15] |

The mapping process takes its start when the GP returns a new generation. Starting with the first individual of the population, a rule for calculating the remainder is being applied to each of its codons.

(1)

“c” is the codon value, and “r” - the number of possible choices of a non-terminal symbol [4].

For example, in the case shown in Fig. 7, let the next term “N” be <factor> and c = 10, then calculating 10 mod 5 = 0, we get that <factor> becomes <identifier>. The cycle repeats, moving to the next codon value. The process runs until one or more of the following conditions are satisfied: 1. all members of “N” went through the mapping process and turned into “T”; 2. the mapping process has reached the end of an individual's genome. Then the wrapping operator is applied which starts the process of reusing the genome; 3. the limit of iterations of the wrapping operator is reached. In this case, the individual is associated with the lowest value of the "fitness" function.

When GP reaches the limit of generations, it returns an answer written in an arbitrary language [5].

## Weibull Distribution. Wind Speed Modeling

Weibull distribution (WD) is recognized as one of the best worldwide known distributions. Regarding the various domains of its applicability [1], WD provides well-fitted approximations in most of the cases. In the present paper, WD is utilized in the context of Geophysics. [16-19]

### Weibull distribution with scale, shape, and location parameters

The general form of WD3 is shown in equation (2), where is the location parameter. The two-parameter Weibull distribution (WD2) is a particular case of WD3 with , where is the exponential repartition (ER) with , and [2].

Equation (3) is the definition expression (DE) for , based on the ER, with and , is strictly positive, measured in , being in resemblance with . is the MWS from the measured values (MV) [19].

(2)

(3)

Properly, has three forms of DE [2]. The reliability function (RF) (4), the distribution function (DF) (5) and the probability density function (PDF) have a different shape comparing with WD2. The first branch of each system is similar to the corresponding function in WD2.

The system (6) is the PDF with , , , and [2]. In DF, is derivable in only for , and, as a consequence, is almost sure, in the set of real numbers excluding the value of .

Substituting in system (6), being as a function of and , PDF with three parameters (7) is obtained.

PDF (7) is fundamental, especially because the algorithm proposed in the case study is based on it. By introducing the initial MV of WS in (7), without forgetting that is the MWS, the WSM will be obtained. However, and should be estimated by applying MLM [20]. Therefore, the estimated values of and , together with the initial measured values, are introduced in the algorithm presented in the case study.

## Maximum Likelihood Method

In many research studies are utilized different methods, including MLM, Method of Moments or Least Squares Method, in the interest of estimating the shape and scale forms [3], [20-22].

MLM takes part in the Rao’s lemma, where the maximum likelihood estimator (MLE) is the partial maximum point of the maximum likelihood function [22]. The MLE is the second-best estimator after the efficient estimator [22]. Thus, MLM provides the most suitable approximations for and . Based on the PDF from WD2, by applying MLM, the estimated form of scale parameter (8) is obtained.

## Analytical Equation of Wind Energy Production

In Analytical Equation of Wind Energy Production (9) are introduced the estimated values of WS, where is the power, is the rotor swept area exposed to the wind, is air density, is WS estimated value, is the coefficient of performance, is the generator efficiency, and is the gearbox efficiency [3].

Based on WSM and (9), wind energy production modelling could be achieved.

# RESULTS

In the military context, are considered two different places, Safed and Nairobi, characterised by contrasting climate. The wind speed modelling and the comparison between the measured WS values, and the estimated ones, both depending on the time, are considered. Data regarding geographical positioning and WS measurements, presented in Fig. 7, is for 01/11/2020, 1:00 - 23:00 [28], [29].

Safed is located in the northern extremity of Israel, being framed between 32°, 57’, 74” n. lat. and 35°, 29’, 45.6” e. long., having a Mediterranean climate [23], [24]. Nairobi is located in the southern part of Kenya, situated between 1°, 17’, 11.0004” s. lat., and 36°, 49’, 2.0028” e. long., being characterized by a highland subtropical climate [25-27].

In the algorithm in Fig. 8, MLM was implemented to approximate , corresponding to each , from the interval considered initially. is interpreted as a divided in three intervals variable climate zone coefficient, where values 3/2, 2, and 3 are corresponding to the predominant climate. The intervals are: , , and , where is an intersection coefficient equal to 0.05.

Figure 7. Wind speed variation

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| |  |  |  | | --- | --- | --- | | Figure 8. Maximum Likelihood Method algorithm | Figure 9. File storage | Figure 10. Wind speed estimation algorithm | |  |

In Fig. 10, the algorithm performs a speed estimation based on and , along with. was chosen manually, together with the corresponding . These values are introduced into PDF (15) for obtaining the WS distribution. The commented part is the base of a transition to the non-linear control algorithm. The program performs all the evaluations and creates file storage, shown in Fig. 9. Filenames indicate stored content: “b1”-“b3” files are estimations; “se” files contain WSM; “ws” files store measured data. The full code can be found on GitHub [30].

In Fig. 11, there are exposed the estimated WS. These results were obtained using only one proper value of and the corresponding . This suggests that the stated problem should be automatized by GE, which will perform the estimation based on the majority of natural variables, involved in the process.

Figure 11 a. Estimated wind speed distribution for Nairobi

Figure 11 b. Estimated wind speed distribution for Safed

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| Figure 12 Code block of a grammar (BNF) | Figure 13 Logic tree-scheme of GP [31] |

In this case, the grammar for the future GE algorithm was developed. In Fig. 12 is presented a context-free BNF grammar, that represents a generator of mathematical relations similar to ones shown as a model in the Fig. 13.

In the first two lines of grammar, function itself and simple mathematical operators are defined. Grammar states that the output relation will estimate “c” as a function of time, “t”. In the third line, environmental variables are exposed. These are: “I”, solar radiation; “T”, ambient temperature; “P”, atmospheric pressure; and “R”, relative humidity. Lines 4 to 13 explain intermediate actions [31].

With the help of the open-source BNF parser, these output examples were obtained:

These relations, evolving in a non-linear evolutionary algorithm, will converge to a one precise result which describes best current climatic situation is a set zone.

# Conclusions

Summarizing, is proven that WD3 applied with BIA’s provides great estimations. Furthermore, considering , and varying with time, respectively with measured WS, more accurate normalized fittings are obtained. This modeled data might be utilized for estimation of energy production at minimum wind speed implying demanding calculus.

This fact leads to the idea of using a special self-learning modern algorithm. The almost unlimited number of permitted natural variables to introduce, with the help of automated big-data analyzer based on GE, will provide long-term predictions. Thus, a mobile wind turbine in a medical military camp is proposed for a future research.

Moreover, the idea of the creation of a visual simulation in one of the popular gaming engines to check the reliability and sustainability of current discovery is reasoned. Implementation of all major natural parameters will allow observing of close to real system behavior. Consecutively, a real mobile wind turbine project might be developed. Starting with just a scaled model it can become a completely reimagined type of alternative energy production device.

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