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Bayesian Analysis Of A CFD Model To A Wind Turbine Made Of Heliocarpus Wood

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***Abstract*—Heliocarpus appendiculatus Turcz (Jonote) is a rural tree used as firewood and for the production of agricultural tools. The bark contains long and resistant fibers that are used in the production of handcrafts and amate paper. This tree is abundant, of very fast growth and both easy and fast production in warm regions. Taking into consideration, the above characteristics of the Jonote wood was established this research with the purpose of knowing the mechanical properties of the wood, visualizing its use for the wind turbine. We were designed a wind turbine and simulated using a CFD model for obtained the effects of environmental conditions compared with conventional woodwind turbine. We analyze the environmental conditions within a wind turbine in order to obtain improvements in its design. Geometry in an air generator is influenced for the material density. We can use BN models as an analytical tool to improve the design of wind turbines. The results demonstrated that the Jonote wood more superior to the conventional wood of wind turbines. The results of this study will considered for future designs in countries with warm climate.**

Keywords— eolic energy; CFD; Bayesian classification; Jonote.

I. INTRODUCTION

The red Jonote is a native tree from the tropical humid regions of America. Its scientific name is *Heliocarpus appendiculatuz Turcz* and it is distributed from México until Central America and Peru [1]. The knowledge of Jonote wood nature, its characteristics, its behavior, and its mechanical properties are so important for establishing and, at the same time to carry out a good use of this material. Regardless of the species, according to Fritz-Duran, we consider that the wood as a biological, anisotropic, or hygroscopic material [2]. In this regard, it is a biological material because its structural made mainly of both cellulose and lignin polymers.

The wood of this tree can be biodegraded by the attack of fungus and drilling insects, like the termites. It is an anisotropic material because its physical and mechanical properties are different in every direction [3], which in turn are due to both, the tubular structure and its concentric successive layers (rings). Nevertheless, could be considered as orthotropic due to the longitudinal axis of the trunk is perpendicular to the growing radial direction of the rings, and also perpendicular to the tangent of each one of those rings. In this regard, for determining completely the resistance and therefore the applications of the wood it is necessary to determine the mechanical properties distributed along of three different directions.

In addition, it is a hygroscopic material because it has the ability to capture water from the environment and release it to the same, which depends mainly on temperature and relative humidity of the environment. This behavior determines and changes in the dimensions and deformation of the wood [2].

A vertical axis wind turbine was provided, using a CFD model form urban areas by Suffer *et al.* [4]; in current new design, the power generated depends on the drag force generated by the individual blades and interactions between them in a rotating configuration.

A CFD vertical axis wind turbine operation in unsteady wind conditions have been conducted by Danao *et al.* [5], which validation of the numerical model was carried out by comparison to experimental data of a wind tunnel scale rotor. The performance of the VAWT under fluctuating winds was investigated and results show a dependency to Reynolds number. Increasing wind speeds causes blade lift to increase more rapidly than drag resulting to higher torque values. Deviation of instantaneous rotor CP from steady wind performance curve was seen. Rotor cycle CP matches steady wind values at the corresponding mean tip speed ratio.

In general have been enormous efforts devoted to the analysis of wind turbines using CFD, however, CFD models are not allowing us to predict the relationships of variables involved and therefore a total process optimization [6]. Thus, the aim of this study was to evaluate wind turbine made of two different woods, using Bayesian analysis of a stationary CFD model; to determine the best features for the design of a wind turbine made of Jonote wood.

II. TEORY

Expected probability distribution of output variables (eq. 1) is determined by the algorithm of solution of the BN. This technique has been used to identify relationships between seemingly indeterminate variables, describing, and quantifying these relationships even with a set of missing data [7, 8].

$$P(x1,...,xn) = \prod_{i=1}^{n} P(xi\,|parents\,(xi)) \qquad (1)$$

The result of this calculation (eq. 2) depends on the probability distribution of the input variables. BN is a joint probabilities distribution of a collection of discrete random variables [9].

$$P(cj\,|\,xi) = P(xi\,|\,cj\,)\,P(cj\,)\,/\,\,k\,P(xi\,|\,ck\,)\,P(ck\,) \qquad (2)$$

The aim of BN structure learning is to find a configuration that best describes the observed data. Statistical machine learning methods have been applied in the Bayesian statistics; however, machine learning can employ a variety of classification techniques to produce models other Than BN. The number of possible structures of direct acyclic graph for searching is exponential in the number of variables in the domain (eq.3). Machine learning can be seen as an attempt to automate some parts of the scientific method by mathematical methods.

$$f\,(n) = \sum_{i=1}^{n} (-1)i+1Cin\,2i(n-i)\,f(n-i\,) \qquad (3)$$

In supervised learning algorithm produces a function that establishes a correspondence between inputs and desired outputs of the system, using a node class. En unsupervised learning all the modeling process is carried out on a set of examples formed as just by logging into the system.

The simple Bayesian classifier (Naive Bayes classifier, NBC) assumes that attributes are independent of each other given the class and the probability.

We can be obtained by the product of the individual conditional probabilities each attribute given the class node.

When we have complete and sufficient data for all variables in the model, is relatively easy to obtain parameters, assuming the structure is given. The most common method is called maximum likelihood estimator (EM) under which the probabilities based on the frequency data are estimated.

The most representative method of the score-and search based approach is the K2 algorithm. The algorithm starts by assigning each variable without dependent relationships (parents). It then incrementally adds a parent to the current variable which mostly increases the score of the resulting structure. When any addition of a single parent cannot increase the score, it stops adding parents to the variable. Since an ordering of the variables is known beforehand, the search space under this constraint is much smaller than the entire structure space, and there is no need to check cycles in the learning process. If the ordering of the variables is unknown, we can search over orderings [10, 11].

III. MATERIALS AND METHODS

The analysis was developed by CFD ANSYS FLUENT 14.0 software; the simulation was performed according by De la Torre-Gea *et al.* [12] with the next faces:

a) Continuous flow discretization
b) Momentum equations Discretization in nodes function.
c) Solve of the algebraic equations system.

To analyzing the relationship between variables, we used ELVIRA system v 0.162 in three stages, suggested by Ortiz-Vazquez [13]:

1) It is carried out using the algorithm of allocation "to mean" to complete the series of partial data. This algorithm replaces lost or unknown values, the mean values for each variable. This method requires no limits and involves discretizing the massive data by the algorithm using six intervals with the same frequency.

2) According to Espinoza-Huerta *et al.* [6], the best Bayesian network structure is developed using K2 algorithm with 5 parents and without restrictions.

3) We performed dependency analysis to get the topological structure of the network, which represents the causal variables and their dependencies. After obtaining a parametric learning network, we calculated the conditional probabilities variables that show the relationship or dependence.

IV. RESULTS AND DISCUSION

Numerical approximation to CFD model is show in Figure 1, to indicate the speed air gradient into the wind turbine made of a) conventional wood, and b) Jonote wood.

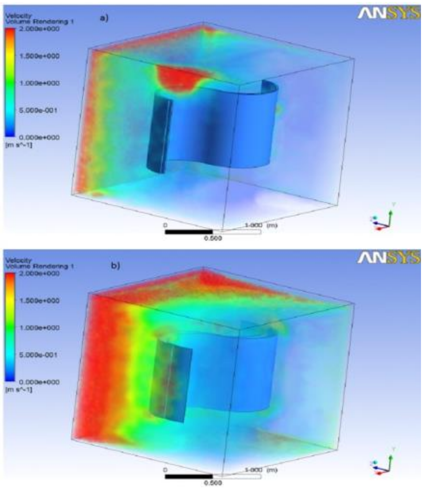

Figure 1. *Speed air into wind turbine made of a) conventional wood, and b) Jonote wood.*

In Table 1, we could see the rate values to the variables that show significant differences between the materials of wind turbine. When the speed air is increased, opposition force to the generator decreased and the mass flow increased too. Those three variables are related with the density of the material employ in the generator; conventional wood density was 7 kg/m^3, and Jonote wood density was 2.5 kg/m^3.

Table 1. Rate values of CFD models.

Type of wood	Speed (m/s)	Mass (kg/s)	Forze (N)
Conventional	0.62	$1.9e^{-3}$	0.0
Jonote	1.51	$13\ e^{-3}$	[illegible]

The BN models of two types of wood show a similar structure, therefore, the main difference between the two types of materials is the wind speed flow in conventional wood is independent of the mass flow and the opposition force, thereby Jonote wood is depend to the wind flow and its opposition force is less than conventional wood, because its density is less, how is shown in Table 2.

Table 2. Conditional probability of mass flow to maximum speed.

Type of wood	Value	Probability
Conventional	$1.9\ e^{-3}$	0.84
Jonote	$13\ e^{-3}$	0.44

V. Conclusion

Due Jonote wood presents less density, it is ideal for ser use in devices to require less height and, according to mechanical properties of compression, tense and static flexion. The Jonote tree is resistant specie to the airflow, and its wood is resistant to the force produce for the radial movement to the turbine. The BN models can be use how design tool to develop wind turbines. The BN models are economic methods for analyze CFD models because no need great informatics resources, and increases precision, and including the likelihood using inferences to quantify dependence or independence degree between interest variables.

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