Mining Sequential Pattern of Multi-dimensional Wind Profiles

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Abstract

Wind has become increasingly important as a source of energy although the generation of wind energy is quite erratic because of its changeable nature. For a given location, wind speed and direction change over time and at different heights. Previous studies have discovered different pattern of wind profiles, however an improved understanding of its spatial, temporal and variation in heights is still lacking. Moreover, there is little prior information available to describe different form of wind profile patterns which frequently occurred in temporal wind dataset. In this paper, we propose a sequential pattern mining approach based on the Linear time Closed pattern Miner sequence (LCMSeq) algorithm for discovering wind profile patterns. This method involves cross-relationships among multiple dimensions associated with a particular space, time and height from the temporal wind dataset. The proposed approach was tested using Dutch 6-hourly wind speed and direction data for the period 1 January 1990 to 31 December 2013. This data extracted from the ECMWF's ERA-40 reanalysis data provides values at six pressure levels (above ground heights). Results provides relevant and understandable wind patterns within the first 290 m over the ground surface.

Keywords: Wind speed, wind direction, wind profile, sequential pattern mining, multi dimensions.

1. Introduction

Wind has become increasingly important as a source of energy and has the advantage of being less polluting than other sources. However, the generation of wind energy is quite erratic because of its intermittent nature (Jung and Tam, 2013). This intermittent nature can be observed through time and in space. Moreover, wind speed tend to increase with altitude and wind changes its direction due to Coriolis forces and other (atmospheric) effects (Emeis et al., 2004).

For a given location, the changeable characteristics of wind speed and direction over time and at different heights could generate recurrent patterns. The identification and study of such patterns might provide valuable information (Tamura et al., 2001). Earlier studies of wind profile patterns include shape-dependent characteristics of wind profiles (Clobes et al., 2011), vertical wind profile characterized by local maxima (Kettle, 2014) and parameterization approach using power law and logarithmic profile for analyzing wind profile (Pérez et al., 2005). Although wind profile characteristics have been (extensively) studied using these methods in various region, an improved understanding of its spatial, temporal and variation in heights is still lacking. Moreover, there is little prior information available to describe different form of wind profile patterns which frequently occurred in temporal wind dataset.

This understanding is important for improvement of various activities such as energy production (Landberg, 1999), civil engineering applications (van Nunen and Persoon, 1982) and pollutant dispersion (Gorlé et al., 2009). It is, therefore, useful to discover wind patterns that represent cross-relationships among multiple dimensions (i.e. spatial, temporal and height). Data mining (DM) methods are particularly appropriate for discovering interesting and previously unknown, but potentially useful patterns (Han et al., 2012).

Sequential pattern mining allows the discovery of patterns that consist of items in sequence arranged in specific order and time related. Sequential patterns can be used to express the wind condition by providing multi-dimensional information associated with a particular space, time and height. In other words, such patterns contain sequences of different intensity of wind through height as well as the location and the time of occurrences of the patterns. These wind patterns can provide essential information to evaluate wind power production either at single hub-height or within the swept rotor area of wind turbines (Wagner et al., 2009). Therefore, this study examined the following questions: How the wind profile patterns can be extracted from the temporal wind dataset in multiple heights?, how the wind profile patterns are distributed and in which locations are exposed to the most prevailing wind profile pattern? and do these happen during the seasonal or diurnal timing?, and how the discovered patterns can determine the preferred height of strong wind speed for wind turbine?.

This paper aims at demonstrating an alternative method for assessing local wind condition involve above the ground surface that exhibited high frequent wind patterns in a spatio-temporal manner. The proposed multi-dimensional sequential pattern mining method was utilized for identifying wind profile patterns from the temporal wind dataset. The proposed method provides relevant and understandable wind patterns within the first 290 m over the surface.

2. Material and methods

We have used wind time series from the ECMWF's ERA-40 reanalysis data, which contain the *u* (eastward) and *v* (northward) orthogonal components of the wind at six different pressure levels (1012, 1009, 1004, 998, 989, and 980hPa) (Figure 1). The *u* and *v* vectors were converted into speed and direction. There are four instantaneous values available in each day: 00:00, 06:00, 12:00 and 18:00 UTC and the selected dataset covers a period of 24 years (1 January 1990 to 31 December 2013). Our study area is restricted to the Netherlands, which lies between latitudes 50° and 54°N, and longitudes 3° and 8°E. The spatial resolution of the wind data is 0.125°x 0.125°(lat/long).

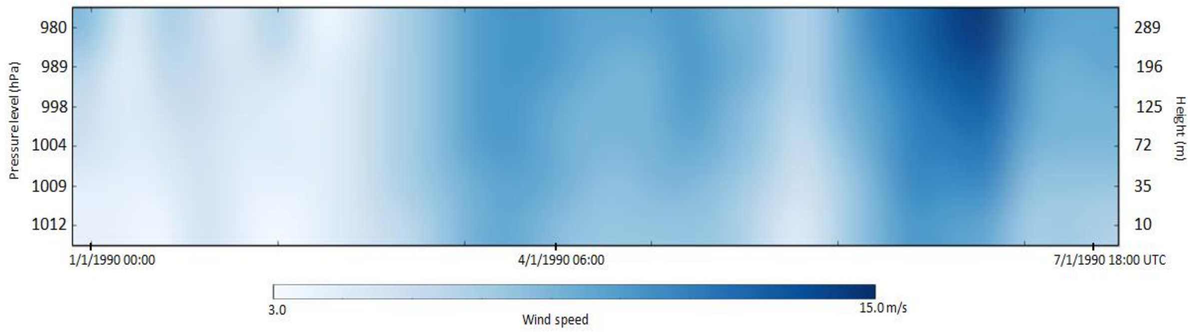

Figure 1. Time-height plot for wind speed profile generated from ECMWF dataset.

To extract the wind profile patterns, we have set up a workflow based on sequential data mining that ingests the multi-dimensional wind dataset as sequences. Previous sequential pattern mining studies have some shortcomings. Firstly, the nature of the join operation (across different dimensions) can increase the length of each sequence and the number of items might become too large (Peng and Liao, 2009). Secondly, using a dimensional partitioning method and wild-cards can generate too general patterns and increase the search space during the mining process (Raïssi and Plantevit, 2008). Finally, the mined multi-dimensional sequential patterns could contain empty sets in multi-dimensional sequential patterns because of unmatched companion (Peng and Liao, 2009). Hence, we proposed a new approach that enables to mine the whole dataset and that might overcome those limitations. For this purpose, the Linear time Closed pattern Miner sequence (LCMSeq) algorithm is constructed to search for significant frequent sequential wind profile patterns from the temporal wind speed and direction which associated in six different heights. LCMSeq is based on the backtracking algorithm where the computation time is generally short because it using simple arrays technique for frequent searching (Uno et al., 2004). In order to extract the patterns, three constraints comprise of minimum support, length of the sequence and sequence gap are imposed in this algorithm. To gain insights of the mined multi-dimensional sequential patterns, visualization techniques are used too. Figure 2 illustrates the overall method proposed in this study.

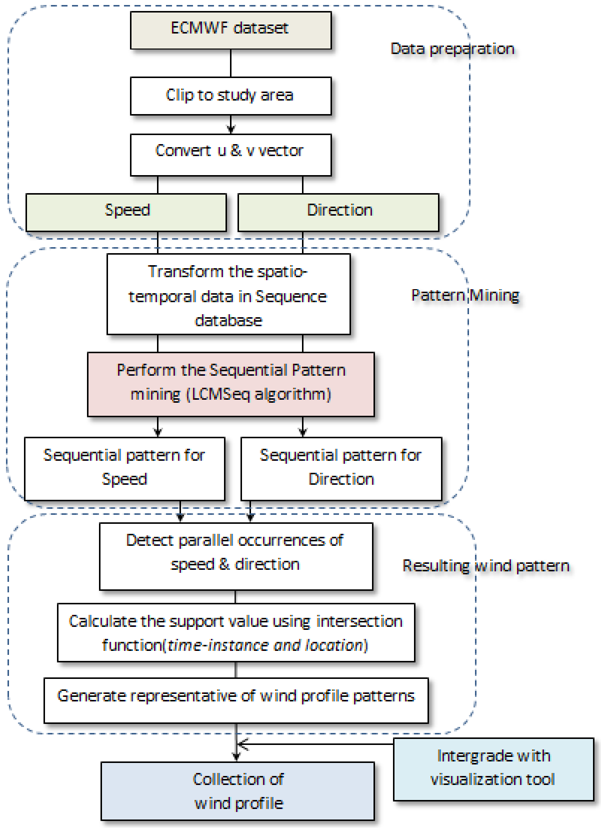

Figure 2. Methodology for multi-dimensional sequential pattern mining for wind dataset.

3. Preliminary results

Figure 3 shows examples of the obtained (preliminary) results. This figure illustrates the distribution of sequential wind profile patterns (with speed and direction) that occurred in space and time according to the wind heights. There are five different wind profile patterns in the selected time moment (1-1-1990 12hr).

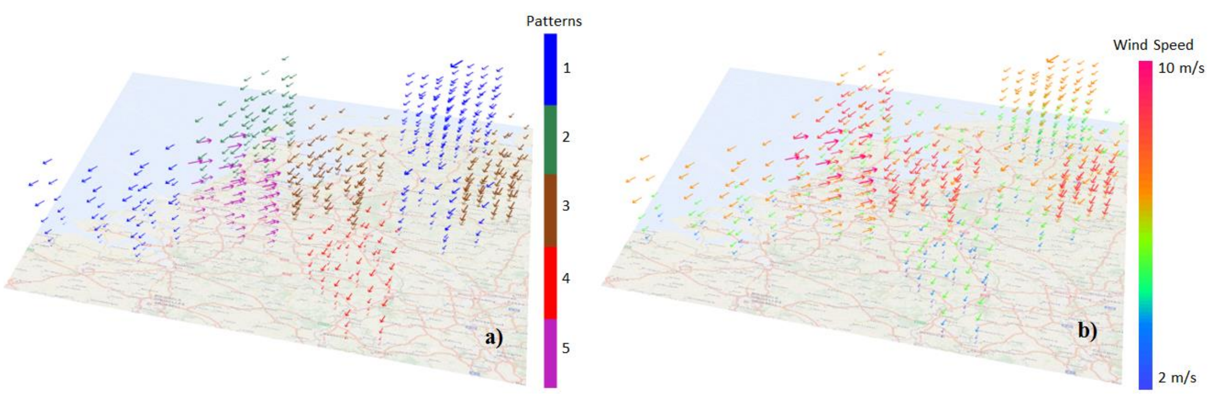

Figure 3. Wind profile pattern occurrences in space and time; a) Five different colors (legend colors) are assigned to each wind profile pattern to distinguished their differences and b) Wind profile patterns are visualized according to their speed intensity

base on colors (legend color) and the size of the arrow (small arrow to larger arrow indicate the speed from low to high).

These patterns may hold important information such as preferred height of strong wind speed which could facilitate for identifying suitable location for wind turbine. From the extracted patterns, we observe the wind directions are nearly uniform. Most of the time the wind blows to the Southwest direction. Furthermore, the wind profile patterns (Figure 3) can be grouped looking at the different characteristics of wind speed (increase, constant and decrease with height). There are three main patterns: 1/ comprised of patterns 1 and 5, which shows a monotonically increasing wind speed with height and with values ranging from 2 to 8 m/s; 2/ pattern 4 has a fairly constant wind speed (3 to 4 m/s) and 3/ pattern 3 shows wind speed values that tend to decreased at higher level of altitudes (above 125 m). Among these patterns, local maximum within the wind profiles are also observed. The local maximum represents wind speeds at a single height is greater than those at below or above measurements. This characteristic can be observed in pattern 2 that has local maximum (6 m/s) at 196 m height. Since this paper focuses on the extraction of wind profile patterns, it is essential to further explore the mined patterns in a future study. Therefore, we can gain more comprehensive understanding of the local wind conditions and to provide adequate wind resource information for assessing suitability site for wind farm.

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