Augmented Reality for Windy Cities: 3D Visualization of Future Wind Nature Analysis in City Planning

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Abstract

Effective government management, convenient public services, and sustainable industrial development are achieved by the thorough utilization and management of green, renewable resources. The research and the study of meteorological data and its effect on devising renewable solutions as a replacement for nonrenewable ones is the motive of researchers and city planners. Sources of energy like wind and solar are free, green, and popularly being integrated into sustainable development and city planning to preserve environmental quality. Sensor networks have become a convenient tool for environmental monitoring. Wind energy generated through the use and maintenance of wind turbines requires knowledge of wind parameters such as speed and direction for proper maintenance. An augmented reality (AR) tool for interactive visualization and exploration of future wind nature analyses for experts is still missing. Existing solutions are limited to graphs, tabular data, two-dimensional space (2D) maps, globe view, and GIS tool designed for the desktop and not adapted with AR for easy, interactive mobile use. This work aims to provide a novel AR-based mobile supported application (App) that
serves as a bridge between three-dimensional space (3D) temporal wind dataset visualization and predictive analysis through machine learning (ML). The proposed development is a dynamic application of AR supported with ML. It provides a user interactive designed approach, presenting a multilayered infrastructure process accessed through a mobile AR platform that supports 3D visualization of temporal wind data through future wind analysis. Thus, a novel AR visualization App with the prediction of wind nature using ML algorithms would provide city planners with advanced knowledge of wind conditions and help in easy decision-making with interactive 3D visualization.

**Keywords**

Wind speed · 3D visualization · Predictive models · Augmented reality · Green energy · Machine learning · Meteorological data · Mobile App · Planning cites · Wind forecasting

### 15.1 Introduction

The usage of environmental monitoring system accumulates data that extend our knowledge about the current status of the environment. The progressing interconnection of sensors with the quality and quantity of meteorological data has led to an increase in techniques and methods that support interactive visualization and analysis of temporal data (Hart, 2006; Bogue, 2008). Today, environmental scientists and city planners now prefer improved interactive visualization capabilities not only for the historical dataset but also for predictive analyses. There is a gap between the observed environment and its three-dimensional space (3D) digital representation in the user-specified time frame for interactive analysis of temporal wind data. Thus, there is still a dissociation that the planner likely needs to solve for comprehending the situation. The scientific temporal data visualizations are frequently used in support of interactive visual analytics and are well-accepted within the geoinformatics disciplines. The data variety, diversity, and volume have brought forward an impressively large number of methods to deal with various issues related to spatial and temporal aspects, dynamic interactions, and different view types in multiple ways of connecting data with two-dimensional space (2D) maps or 3D globes (Harbola and Coors, 2018). The characteristics of data, voluminous data, multidimensionality, and high spatial distribution contribute to make situation assessment one of the most demanding tasks, both for the user and the platform (Thomas and Cook, 2005). Numerous studies have stressed on the importance of spatial reference of data, while others focus more on the temporal aspect. Depending on user requirements and the nature of the target audience, there are different levels of experience and interests that are amenable to scientific time data (Nocke et al., 2008). It could be standard 2D presentation techniques, both scalar- and vector-based 3D data representations, and mobile GIS combined with handheld software (ESRI, 2004; Lin and Loftin, 1998). Combining the augmented reality (AR) for temporal geoscientific visualization is still yet to be explored. There are studies that deal with unconventional visualizations of urban pollution levels using mobile AR or tripod-
mounted AR system to visualize GIS data designed and developed on a range of human factor studies (White, 2017; King et al., 2005). Mobile visualization offers a solution in that it directly places heterogeneous datasets at different spatiotemporal scales in their accurate spatial and temporal context. AR, while coordinated with ML, is an advantage that speeds up the process and comes up with new good implemented cases that remains a challenge.

In contrast to these works, this paper proposes a combination of visual analysis platform with spatial, temporal, and future prediction information for the user-defined time frame. It comes along as an AR mobile Application (App) for quick, advance, and easy interface. Moreover, mobile display, combined with AR, proposes a natural way to relate abstract content to the physical world through graphic overlays. Interactive 3D visualizations of future prediction methods (which work on the original wind data by taking into consideration the noise) are still required. In this regard, the current study:

(i) Introduces the concept of mobile environmental monitoring using handheld AR.
(ii) Analyzes and describes its associated workflow following an iterative user-centered design (UCD) process.

The proposed AR mobile supported App provides an innovative infrastructure. It enables access to wind datasets for both future and historical data for user-desired time frame in interactive 3D visualization. It enables near real-time data access. The developed App will provide forecast of wind nature and helps to select good sites for wind analysis-related projects. This 3D visualization will devise smart utilization of renewable energy for safe and better city planning. This can help to manage and develop the city’s resources. The remaining paper is organized as follows: The proposed methods and datasets used are discussed in Sect. 15.2 and Sect. 15.3, respectively, and the results are discussed in Sect. 15.4, followed by a conclusion in Sect. 15.5.

### 15.2 Methodology

The proposed method is a technique to visualize the historical as well as future temporal wind datasets interactively. The developed 3D visualization AR mobile supported App is called WindAR (Fig. 15.1). The WindAR supported 3D visualization of the data makes it easy to connect with the temporal wind dataset accompanied by spatial and future prediction information. The WindAR starts with an interactive selection dashboard that provides the user with an interactive way of selecting the location of a sensor. The App offers the possibility to select data of the sensor at the respective location via the name of the sensor from a predefined list or by specifying the coordinates of the sensor. The location is displayed in 3D in the WindAR. The user then selects the desired time frame (day, month, year). The detailed information in terms of 3D temporal wind flow is displayed for the selected time frame. Then, the user could perform the intermediate reset for the input of the section in the dashboard and compare other desired cases visually. This period could be in the past, which is already available in the App database, or in the future. Here, future
values are obtained by predicting wind parameters for very short term (a few hours in the future). 1D Multiple CNN (1DMCNN) (Harbola and Coors, 2019) is used as a regression method to predict wind parameters. The 1DMCNN architecture consists of five individual CNN, each of which has its own input layer and is connected to the two common fully connected layers, followed by the output layer. The output layer uses a linear activation function, while hidden layers use the exponential linear unit (ELU), a nonlinear activation function. The output layer has nine neurons to predict the regression output. Each neuron in the output layer corresponds to an epoch. The 3D visualization of the temporal wind flow supported by AR is created using Unity’s real-time development framework. Unity offers many tools to create 3D applications. It supports all relevant AR platforms (such as Android, iOS, HoloLens) with the same codebase. Unity’s ability to render mesh-based 3D or 2D graphics very quickly makes it an incredibly capable engine for creating proposed spatial, temporal, and user interactive significant mobile AR App WindAR.

### 15.3 Dataset

Stuttgart wind datasets are used in this study. In the corner of Hauptstaetter Strasse 70173 Stuttgart, the historical data of 1987 to 2017 is taken from Stuttgart station sensor.\(^1\) This dataset contains the wind speed and direction with temporal information attached in a 30-minute interval. The temporal meteorological dataset is organized with past data first.

\(^1\)https://www.stadtklima-stuttgart.de
followed by the latest data. It helps to predict wind speed and direction for interactive selection of time frame in 3D WindAR.

15.4 Results

The proposed algorithms were implemented using Python and executed with four cores on Intel® Core™ i7–4770 CPU @3.40 GHz. Stuttgart’s 30-year historical data was used to train and test the regression-based prediction model 1DMCNN, thereby forecasting the wind speed and direction. The interactive WindAR App is a platform to visualize the sensors’ dataset with spatial and temporal information attached, as shown in Figs. 15.1 and 15.2.

In this first version of running AR mobile App WindAR (Fig. 15.3), the .csv files of temporal wind datasets are included in the App itself. During the initialization of this App (starting up), the .csv files are parsed line per line, and useful information is extracted into
two lists of each selected parameter. The first list was a collection of all unique dates without the time in the file, to make user-desired time frame date selection possible. The second more extensive list contains all data entries from the list, including date, time, wind speed, and direction. Once during the run time, the desired time range has been selected. A temporary array with all the required information is generated and visualized in 3D with AR using WindAR. The time complexity of loading and parsing the dataset is given by $O(n)$. The extracted geometry (and background) of the sensor location and the environment are linked to the App using the Vuforia image targets method (Inc., 2011).

3D visualization is done by using Unity’s physical wind system in combination with a particle system. The wind flow is represented by dust particles’ flowing speed according to the magnitude and direction of the real-world temporal.

wind flow sensor measurements. The 3D visualization of temporal wind flow over the sensor location is accompanied by a played wind sound that uses pitches that depend on the strength of the wind. In order to provide close to real 3D visualization in AR platform, the wind flow particles are color-coded depending on the wind strength (blue (less than 2 m/s)→green (2–4 m/s)→yellow (4–6 m/s)→red (above than 6 m/s)) accompanied with the wind flow motion, thus leaving a trail behind (as shown in Figs. 15.4 and 15.5). In Figs. 15.6, 15.7, 15.8 and 15.9 the wind flow particles are color-coded depending on the wind strength accompanied by the wind flow motion leaving a trail behind, as discussed above. Besides, there is a weathercock, which is rotated to show the wind direction purely at the sensor’s location Figs. 15.6.
**Fig. 15.4** Wind flow visualisation color (strength) assignment scheme

**Fig. 15.5** Wind flow color coding scheme ranges

**Fig. 15.6** Wind flow with 3D geometry visualisation accompanied in the WindAR App
15.4.1 Discussion

The proposed WindAR App is an easy and interactive AR technique in which users could scan the sensor spatial location. The user automatically gets detailed information about the sensor’s recording parameters and measurements with respect to the time of the year. AR mobile supported App allows for close to real-time data access. The developed App provides forecast of the wind in a given area, thereby helping in the proper selection of

Fig. 15.7 Wind flow particles trail visualisation in the WindAR App (side view)

Fig. 15.8 Wind color coded flow visualisation in the WindAR App

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sites for wind analysis-related projects. The AR-based 3D visualization enables information on renewable energy use for competent management, safe and better city planning, and development of the city’s energy resources.

15.5 Conclusion

The study of meteorological parameters and their effects has been the attention of researchers in smart city planning to enable thorough use and management of resources that would contribute to convenient public services and sustainable industrial development. Using renewable energy supply would provide a healthy and amiable city, and increased welfare in more general terms. To ensure incorporation into the planning process, the renovation of the existing planning is indeed the most promising field for climate-related intervention. In this paper, we have presented an AR mobile App with quick, advance, and easy interface. It consists of a unique interactive visual analysis platform that combines spatial, temporal, and future prediction information for the user-defined time frame. The authors have stressed the need to include energy-conscious strategies to improve environmental quality. The integration of new knowledge and innovative technologies in sustainable transformation is the motive of this proposed work. The AR-based 3D visualization proposed here could be further improved in combination with a web service that loads the dataset directly into the App from the web server without using .csv files. The authors’ future focus is on fully automatic identification and location detection of these sensors in real time, with sensor data displayed interactively in WindAR App. Meanwhile, the predicted speed and direction has the potential to select a feasible location for the wind sensor installation, and the developed interactive visual analysis of the AR application facilitates the selection. In addition, since the output of the wind turbines is highly dependent on the wind speed and direction, WindAR would provide a foresight for better planning.
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