# Free versus constrained motion for assessing wind turbines' impacts on landscape in virtual environments

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## Abstract

*Wind turbines (WT) are socially controversial because of their visual and acoustic impacts on landscape. The issues remain on one hand, the technical and objective point of view for subjective impacts; and on the other hand the separate static study of visual and acoustic aspects when landscape is multisensory and dynamic. Virtual reality (VR) is here proposed - thanks to immersion and interaction potentialities - as an immersive multisensory and dynamic approach in order to assess WT impacts. For that, a comparison between a real park and the same virtual one is needed to evaluate VR for landscape impacts' restitution. The parks are evaluated using an immersive path-based method (perception in motion).It shows the requirement of multisensory immersion, free navigation and natural physical motion.*

## 1. Introduction

In today's international energetic context, many countries strongly encourage wind turbines (WT) projects. WT energetic gains are barely contested contrary to impacts that create local disagreement; indeed, WT make visual contrast with the rural background and acoustic nuisances in the neighborhood. WT impacts interested many researchers but most of studies are one sensory, non-immersive and non-interactive. Contrary to rural space evaluation methods, some urban techniques use predefined paths on site to immerse the observer in order to study his instant perception; they can be suitable with landscape experience [6].

Virtual Reality (VR) has been involved in landscape and environmental planning thanks to immersion and real-time interaction [7]. It solves many problems classical static non-immersive methods.

The main goal of this paper is to build a multisensory and dynamic approach based on VR able to assess WT landscape; in other words able to render visual and acoustic impacts. In the first part of this paper, we will explain the theoretical framework: landscape concept and methods, WT impacts, as well as VR potentials and limitations for WT studies. In a second step, we will describe the dynamic multisensory and comparative approach used to develop VR for WT landscape. After a description of our experimentations, a third step will present and discuss comparative results.

## 2. Related works

### 2.1. Landscape perception and evaluation

Landscape is a complex system that invites observer's participation and exploration and provides him with information from all directions via multisensory modalities. In this study, we want to determine WT impacts' on landscape. Impact refers to the physical changes that are introduced to a site by a new development activity which is produced and evaluated by individuals. The human *inside* point of view is more faithful to real-life experience than an extended view [8]; it has then been proposed to assess perception thanks to an immersive posture. Landscape perception methods mainly probe visual assessment [7]. Vision predominates in perception but other senses participate: perception is multisensory and in the WT case, both visual and acoustic perception have to be considered.

The ecological approach of perception [4] shows that observer's motion enhances perception. Motion also links time to space information. The path is a common way to study perception in an urban context. It has been shown that an immersive, interactive, multisensory and path-based method is suitable with in rural context [6].

### 2.2. Wind turbines' impacts on landscape

The visual aspect is the main feature of WT landscape but this impact strongly depends of distance. Some windfarm guidelines [9] have identified specific levels of perception for recommended Zone of Visual Influence (ZVI): the *Distant area* (more than 10 km) where WT are not always visible and the nearest objects generally dominate perception. But, in an extended empty landscape, the vision focuses on WT which structure the space. Closer is the *Intermediate area* (between 1 and 10 km): there are two different readings depending on point of view: a frontal and horizontal reading or a lateral and vertical reading. Last is the *immediate area* (a radius smaller than 1 km): WT even more dominate visual perception because of their size. Visual and acoustic impacts are very important.

WT have both mechanical and aerodynamic noise but the aerodynamic one (the friction blade/wind) propagates to hundreds meters around and disturbs neighbors. According to Gamba [10], wind speed must be taken into account: underneath 15 km/h, WT do not turn, between 15 and 20km/h the emergence of WT noise is the most significant because vegetation noise is not still sufficient. Beyond 20 km/h residual noise re-generated by the wind in vegetation is getting more significant that WT noise.

### 2.3. VR potentialities and limits for WT impacts

In digital WT landscape, visual assessment is the most studied and can be improved by adding the moving blades and some atmospheric characteristics [2]. Actually, the acoustic issue is how to reproduce the same perception of different sounds (wind, vegetation, WT...) of an extended space into a closed one?

A digital landscape experience must also involve real-time interactivity. In fact, natural movement is the main interaction issue as a majority of works focus on building visually-realistic but passive worlds. Active physical motion is a particularly potent self motion cue [5]. Scale difference between the virtual environment (several hundred meters) and experimental VR facilities is the actual issue. Some works have used the omni-directional treadmill [3] or the "cyber-sphere" (Warwick University) to provide natural walking but these technologies remain experimental and expensive. One approach has used a tricycle [1] which has been instrumented. Natural movement is provided but needs an available large free space.

## 3. A multisensory and dynamic approach

This state-of-the art shows that the virtual WT landscape has to be – like in real context – immersive (contextualized), multisensory (vision/hearing) and dynamic (free movement). To follow successful urban analysis methods, we adopted the promenade approach (perception in motion).

The comparison between impacts perceived by an immersed observer in situ and impacts perceived in vitro will determine the rendering conditions of impacts and limitations of the methods. In previous work, we had proposed to experiment an interaction with a Wiimote device (constrained non-physical movement) that showed important limitations. Here we try to override those limitations by using a very-low cost instrumented bike.

### 3.1. Procedures and tasks

The in situ and in vitro surveys are similar; they are composed of *commented country walks* inspired of the commented city walks [11] – and questionnaires. 18 participants took part of the in situ survey , 27 in the Wiimote experiment and 4 in the bike pre-experiment.

The *commented country walk* is based on the verbalization of pedestrian's perception: the participant, accompanied by the investigator, is required to walk along the predefined path, to observe and to describe what he feels. The comments are filmed and recorded to remember the participant's behavior in the VE and his 'instant' perception. Comments are transcribed and analysed in order to bring out the visual and acoustic features of WT landscape, to compare between the selected paths and to determine the influence of motion and of the environment on perception. The questionnaires' analysis identifies in a more accurate way the 'remembered' landscape features that marked the participant.

### 3.2. Investigation site: Park of Plouguin

The study park is situated in Plouguin (France) and surrounded by flat agricultural fields and a few hamlets. The 7 WT are streamlined with smooth shapes and colored with light grey-blue in the high part and with a green graduation in the base. They are installed since 2004; 2 paths tally with intermediate ZVI and are frequently visited by tourists and inhabitants.

### 3.3. VR application and experimental conditions

The virtual world includes: 1/ visual perception: blades rotation (path 1 and 2); and an avatar placed 2m front and 1.5m left the camera (only path2 because in path1, he blocks up the frontal perspective). The avatar's role is to enhance visual cues of motion, to give human scale and to guide the participant in the virtual scene. 2/ acoustic perception: the different sounds (blades noise, road traffic, birds and wind) were recorded on site and implemented in virtual paths with respect to reality. In Path1, three sounds were associated to 3 objects (blades noise/blades, road traffic/road and birds noise/central object in the scene); the blades noise was pitch-defined in order to match with the blades rotation speed (12 revs per minute). In Path2, WT were not heard (in situ survey) then only birds and road traffic were implemented. In both paths, every sound has a sphere of acoustic influence and decreases at a certain distance like in the real paths.

The experiment took place in an immersive room equipped with a large rear-projected screen (2.4x1.8m), 4 loud speakers, a computer and 2 video projectors. We decided to place the user at 1.2m far from the screen which ensures a field of view of 90 horizontally and 73 vertically (1:1 scale). The virtual camera is positioned at 1.6m from the digital floor.

The goal of this experiment was to override the difficulties of Wiimote interaction as well as to overcome the problem of using a single screen to visualize WT when people try to look up. We assumed that an instrumented bike could be solution: motion would be natural and as people are bent on a saddle, they are somehow prevented of raising their head. To cope with a very limited budget, we simply used the opto-mechanical sensors of 3 mouses that were plugged to the PC and implemented natural motion with a Virtools building block. Rotation of the rear wheel and of the handlebar were measured to provide realistic natural motion to the user. A third mouse wheel has been fixed on the handlebar and used to control head vertical orientation. The system instrumentation is presented in figure 1.

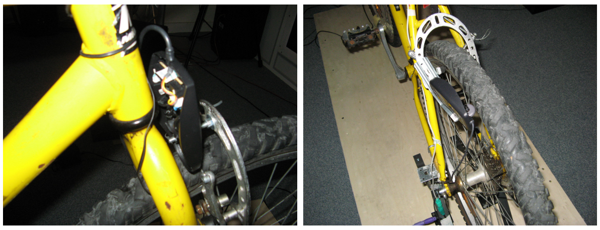

Figure 1. Instrumentation of the bicycle with mouse sensors.

# 4. Results and comparison

This section presents on one hand, the results of the Wiimote experiment and their comparison with the in situ results and on the other hand, the first results of the instrumented bicycle experiment.

## 4.1. Human perception properties

In situ results confirmed that visual and acoustic perception are the most important features of WT impacts. The path-based method also revealed that perception in motion has a significant part in impacts' assessment.

Visual perception was rather similar between real and virtual paths but differed between both paths. In real and virtual path1, most participants were focused on WT (impressive scale (93%) and moving blades' attraction (28%)) and gave positive WT description (modern, elegant) but in virtual path1, the flat vegetation was also of great attractiveness. In real path2, WT dominated visual perception (impressive scale (55%) and moving blades' attraction (88%)) but in virtual path2, all participants focused more on the road perspective than on vertical and tall WT (84%) or moving blades (61%).

The integration of sound was of great importance for immersion sensation in both paths. In real and virtual path 1, acoustic perception was similar and exclusively referred to WT. Most participants classified WT noise as mechanical (airplane, washing machine, etc.) and it was negatively perceived because of its cyclic repetition. In real and virtual path2, acoustic perception referred to wind, birds and road traffic; but in virtual path2, some participants thought that the integrated wind noise was the WT noise (they expected to hear WT).

The comments' analysis also emphasized motion influence on perception. In real and virtual path1, they revealed that WT were seen one by one and that they activated visual and acoustic perception. In path2, WT only activated visual perception but while in real path2, they were seen as a group in the beginning and progressively, participants concentrated on the nearest WT; in virtual path2, the participants looked rather straight ahead (only 3 to 1 WT were visible) and wanted to reach faster the houses at the end.

## 4.2. Environmental properties' influence

The physical factors that influenced paths' perception were the sunlight/clouds couple and the wind. In situ, we noticed that WT drew more attention when the sun shone and the wind force acted on acoustic perception of vegetation and WT. In vitro, only one situation was played yet and the wind force was only perceived in the blades (rotation and noise).

The surrounding shapes and objects influenced path visual perception in the real and the virtual paths. In real path1, the field of view was rather narrow and only opened on a vertical nearby WT but in virtual path1,it was more accentuated by the flat 2D vegetation on both road sides which motivated participants to accelerate. In real path2, the field of view is widely open with a pleasant horizontal rhythm of WT in the background but the virtual path2 encouraged participants to accelerate too because they felt bored in an open unchanged landscape (Figure 2).

Figure 2. Real (up) and virtual (low) narrow field of view (path1) versus extended field of view (path2).

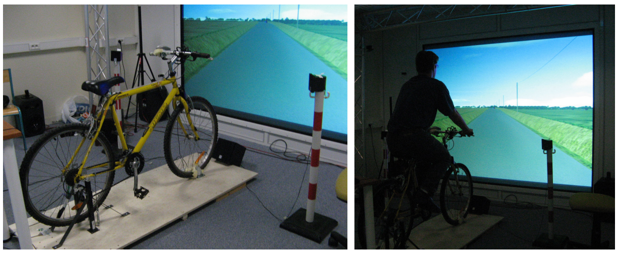

Figure 3. The bicycle-based experiment.

### 4.3. Active motion experiment: using a bike

The experiment is in progress (Figure 3) and adresses some limits of the first experiment: the constrained direction was unpleasantly felt even if free direction was not always needed; although the Wiimote was easily used by all participants, the absence of physical motion was annoying.

First inquiries with the bike validated on one hand, a better sensory immersion thanks to free natural biking (participants reached the WT foot when they wanted to) and on the other hand, an improvement in virtual world interaction: 1/ the participants were no more annoyed because of motion but in path2, they were only bored because of the unchanged landscape and could accelerate; 2/ participants paid less attention to the flat vegetation in path1 because they were biking and were able to accelerate.

Another advantage of the instrumented bike is distance perception. Harris [5] demonstrated that distance is better-evaluated when motion is physically active. Paths are approximately 500m long and the covered distance was estimated between 400 and 500m.

## 5. Discussion

The immersive multisensory and dynamic approach of WT impacts gave rich information about landscape experience (even with the Wiimote) and it was rather similar in both worlds. However, some differences must be discussed.

As far as visual immersion is concerned, participants were satisfied about the 3D model except the flat vegetation in path1. It accentuated the road perspective but it does not disturb impacts' restitution. A screen boundaries limited the field of view, the participant did not know what was happening around until he used the Wii device/bike. In the real site and at the WT feet, when participant looked above to the blades and the rotor, this distance is more than 50m whereas in the virtual experiment it is less than 2m. Consequently, even with 1:1 scale, WT are less impressive than real ones.

On the acoustic point of view, sound improved the presence feeling and showed the needed interaction of visual and acoustic perception. But the wind sensation is still an issue: how to hear wind without feeling the breeze?

## 6. Conclusion and further works

In this paper, we have presented an immersive path-based method which can be used both in real built environments and in virtual environments. The results diversity shows good potentialities of the multisensory and dynamic approach of landscape. Instant perception is rich in sensory information and takes context into account. Besides the natural posture, walking emphasizes the landscape temporal dimension which acts on visual and acoustic perception. The designed VR system rendered most impacts.

Further works will first aim at integrating VR in the project phase of windfarm deployment. For that, it will be important to be able to combine the sensitive approach that we have proposed with other results such as wind potential of the zone, 3D maps of interaction between wind turbines.

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