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Methodology for assessing cycling comfort during a smart city development

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Abstract

Smart city development that encourages more bicycles on the road will pave way for a city with an energy-efficient transport. In this direction, the current work involves developing a cycling comfort matrix based on computational fluid dynamics (CFD). CFD simulations of an urban layout (Niigata city in Japan) under different meteorological conditions (wind directions) enables us to measure cycling comfort through: (a) the Predicted Mean Vote (PMV) a thermal comfort measure and (b) the Turbulence Intensity (TI). Work involves validation of CFD wind prediction with measured experimental data. Results show that during the summer time, the higher wind velocity regions will provide thermal comfort to cyclist (near-zero PMV regions), but such zones also tend to have higher TI (due to high gradients near the buildings at high wind speed) which may be unsafe. This work has the prospect of both aiding in planning of new cycle routes and developing smart urban building layouts.

Keywords: Cycling; Smart City; Comfort; CFD; Predicted Mean Vote; Turbulence.

1. Introduction and objective

A smart city development will need to cater for cleaner and energy efficient transit mediums amidst increase in transport demands from ensuing population growth. To meet these challenges, the smart-city planning authorities would like to develop a city in such a way that the growth in road traffic volumes is absorbed by sustainable transport modes with less car usage (i.e. through a combination of cycling, walking and public transports). Bicycling is considered as one of the most energy-efficient machines for transport, but strong wind conditions arising due to building layouts,land-use and terrain features can make this experience uncomfortable. Currently, smart city planners do not have any objective module to connect the land-use categories, existing and planned cycling routes with meteorological factors like wind. There is a scope to make cycling smarter and comfortable by understanding the influence of changing urban microclimate (like wind conditions and meteorological factors) during city development. The current

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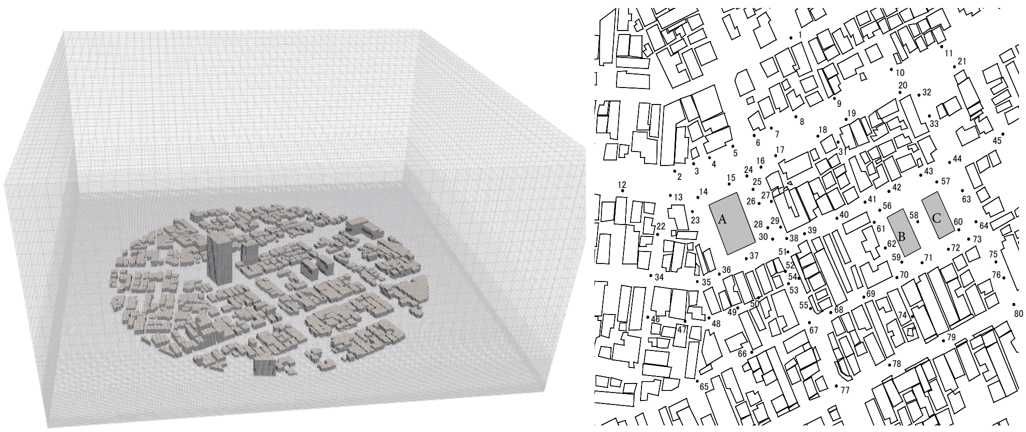
work aims to show case a "cycling comfort matrix" to assess which cycling routes may face difficulties due to (a) changing micro-climate (wind conditions) and (b) urban development. The development of cycling comfort matrix is with the long-term intention to make cycling smarter as cyclists can track comfort associated with cycling routes and make decisions. The work involves conducting micro-scale CFD simulations of a realistic urban area incorporating building layout and nearby terrain features under different meteorological conditions and different urban development scenarios, and analyse the results for developing the cycling comfort matrix. Current literature status shows that a cyclist's perception of dynamic comfort has received scant attention in the scientific community [1]. Ayachi's survey [1] with 244 respondents helped us to understand that a cyclists comfort are guided by certain qualities related to the bicycle components, the road and external conditions (e.g. weather, temperature). To help quantify and measure some of these external conditions, we propose a cycling comfort matrix with two parameters (turbulent intensity and predicted mean vote) which utilizes the wind data computed from hi-fidelity micro-scale simulations involving building. The methods and approach are described below in detail.

2. Approach and Methods

Computational fluid dynamics (CFD) simulations provides us with information on wind velocity, pressure, turbulence and temperature in a micro-scale urban surroundings. This information can help us to develop a cycling comfort matrix. The details of numerical techniques and set-up for simulations are given below:



(a) Geometry and Mesh (b) Measurement point locations

Fig. 1. Layout and Computational domain

2.1. Domain of Analysis

CFD simulations have been conducted over a scaled down (1/250th scale of the original) Niigata urban landscape (see figure 1). The urban landscape here is an actual city block in the Niigata city,Japan involving several low-rise houses jammed closely together with some high rise buildings (a 60m high Building A and two 18m high buildings B and C) as seen in figure 1). The cycling paths are along the roads besides the buildings in the city. The wind tunnel experiments are also conducted at 1/250th scale of actual model [2] and the data are available for validation of the CFD (see locations of measurement points in figure 1. This validation and geometry was earlier simulated by using k-ϵ model [2]. In this work, we use a $k-\omega$ SST turbulence model[3] based on Reynolds Averaged Navier-Stokes. For brevity, the equations are not described here. The wind inlet conditions for wind tunnel are represented by a power law exponent of 0.25 and the results are used to validate the CFD measurements. Scalar wind velocities at 8mm above the wind tunnel floor (2m above the ground surface in real scale) were measured by multi-point thermistor anemometers. The building walls are treated as a no-slip boundary and employs a wall function based on Spalding's law [4] that gives a continuous kinematic viscosity profile to the wall over wide range of y^+. This is required because the average