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Analyzing The Impact Of Driving Behavior At Traffic Lights On Urban Heat

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Abstract

Studies have shown that traffic contributes up to a third of the anthropogenic heat produced in urban areas. To study localized effects of traffic on urban heat, conventional thermodynamic models are only of limited use because of their computational costs or low resolution. We are using our recently proposed Cellular Automata (CA) based Anthropogenic Heat Simulation to examine heat effects of dynamic traffic flow in close proximity to traffic lights. In this work, we use our method to study the impact that driving behaviour near a traffic light can have on urban heat.

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1. Introduction

The term Urban Heat Island (UHI) describes urban and metropolitan areas with measurably higher temperature compared to their surrounding rural areas. In tropical cities with high amounts of sun radiation year round and waste heat from air conditioning this difference can reach up to 7°C. For Singapore, [1] estimates that traffic alone is responsible for up to 30% of the anthropogenic heat emissions, making it the second highest contributor after built environment. This is reason enough to have a closer look at the contribution of traffic to UHI, possibly leading to mitigation strategies. The past has seen development of numerous thermodynamic models for heat flow and heat emissons. Computational Fluid Dynamics (CFD) can yield very accurate and detailed representations of local physical processes. Other models like the Urban Energy Balance (UEB) take a more macro scale approach and aim at quantizing energy propagation rather than localizing it. The challenge in simulating the heat emissions from traffic is that it falls into a niche between both extremes. CFD models are only viable in static scenarios and energy balances like the UEB lack all spatial information. We recently proposed a Cellular Automata based Traffic Heat Simulater (THS) [2] that can address this issue. In this paper, we present a more advanced version of the THS and use it to analyze the impact of driving behavior on anthropogenic heat. The paper aims to highlight the impact that Intelligent

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Transportation Systems of the future can have on UHI and also the usefulness of our technique for studying these impacts.

2. Related Work

Numerous models have been proposed for simulating propagation of thermal energy. They can be distinguished by their level of detail and the methods they use. CFD models are most famous for their accuracy [3,4], which comes at a cost. This kind of simulation is generally aimed at small scale scenarios, e.g., individual vehicle parts. It is also not suited for application in dynamic scenarios, like traffic flow on roads or intersections. On the other end of the spectrum UEB models are designed to simulate energy transfer over large urban areas [5]. In contrast to CFD there is no spatial propagation modeled is the UEB is entirely focused on quantifying the energy exchange. The work of [6] examines heat propagation within the pavement layer. They propose a network-based model of heat dissipation inside pavement layers using a *finite difference mesh*. Similar to a CA, the pavement layer is modeled in form of a grid where the thermal energy is propagated between neighboring nodes. Although this work does not include any energy fluxes from vehicles it offers a valueable approach of how solar radiation and other meteorological processes can be represented in a grid based model. Other emission models have been conceived for qualitative measurements instead of spatial ones. The work by [7] explores heat emissions on a local level. While only making quantitative statements about vehicle heat emissions and omitting spatial propagation, it does deliver a detailed description of the involved processes.

The model used in this work discretizes space and time. Furthermore, the state space of a CA model is also discrete and finite. In each time step the values of all cells are updated synchronously based on the values of cells in their neighborhood. Depending on the type of neighborhood (i.e., von Neumann, Moore), and the type of lattice (triangular, square, hexagonal, etc.), the exact number of cells in the neighborhood of a given cell can vary [8]. CA models are popular for modeling systems that would be complicated to model mathematically but can be approximated reasonably by a simulation model that is discretized in space and time. For example, indoor egress simulations use CAs to approximate fire/ smoke propagation [9]. Driver behavior patterns and variations thereof are a widely accepted way of regulating fuel usage and, consequently, carbon emissions [10,11]. In a similar vein, in this work, we use the THS to examine the effect that behavioral patterns in driving can have on *heat* emissions.

3. Urban Traffic and Thermodynamics Model

The system we use consists of two main components: traffic generation and the physical simulation. The former is done by SEMSim, a nanoscopic agent-based traffic simulation which can simulate road going traffic up to a scale of a whole city [12,13]. Nanoscopic in this context designates the high level of detail of the simulation. Each vehicle is considered an autonomous agent and all its subcomponents simulated individually.

The cellular automaton approximates the spatial propagation of thermal energy by discretizing the simulated space. The computational model is explained in more detail in [2]. Here we briefly give an overview of the workings of the model and focus on the differences. It uses the vehicle power output and traces generated by SEMSim. With this information the cellular automaton can then project emissions into the discretized space and simulate the heat propagation there. Important here is that cell size can be varied to balance between accuracy and computational costs. Smaller cells increase the accuracy of the physical simulation while considerably increasing the required runtime. Within the context of this work we are using a straight one way road section for the sake of simplicity. However, in general the CA can process any kind of two-dimensional road layout and is not restricted to one-way roads.

To cope with the extensive amount of computational time and memory space required to run this automaton, the CA was modified to make use of a dynamic grid resolution. At simulation start the CA consists of a single large cell. If a temperature change is detected in the system, i.e., by vehicles entering the scene, the inital single cell is split into subcells according to the octree hierarchy [14]. This means physical processes can be locally simulated in the desired higher resolution while unaffected areas with homogeneous temperature remain clusters of low resolution, as shown in Figure 1. Furthermore free convection has been remodeled to better fit into the CA concept as well. Instead of considering whole columns of air at a time for convective force, each cell now individually regulates its horizontal in- and outflow of energy. This happens according to temperature and density differences between