项目编号： 2019YFE0127400 密 级：公开

国家重点研发计划
项目任务书

项目名称：	面向国际重大灾害的 ChinaGEO 应急数据与灾情信息服务
所属专项：	政府间国际科技创新合作
指南方向：	3.8 地球观测组织（GEO）合作项目
推荐单位：	浙江省科学技术厅
项目管理专业机构：	中国科学技术交流中心
项目牵头承担单位：	浙江大学 （公章）
项目负责人：	张丰
执行期限：	2020 年 12 月 至 2023 年 11 月

中华人民共和国科学技术部制

2020 年 11 月 21 日

0002YF 2019YFE0127400 2020-11-21 21:54:14

项目基本信息表

项目名称	面向国际重大灾害的ChinaGEO应急数据与灾情信息服务				
项目编号	2019YFE0127400				
所属专项	政府间国际科技创新合作				
指南方向	3.8 地球观测组织（GEO）合作项目-地球观测综合应用研究				
密级	公开		国内单位数	2	
项目类型	□基础前沿□重大共性关键技术■应用示范研究□其他 □青年项目				
经费预算	总预算 481.00 万元，其中中央财政专项资金 481.00 万元，地方财政资金 0.00 万元，单位自筹资金 0.00 万元，其他渠道获得资金 0.00 万元				
项目周期节点	起始时间	2020年12月	结束时间	2023年11月	
	实施周期	共 36 个月	预计中期时间点	2022年06月	
项目牵头承担单位	单位名称	浙江大学	单位性质	大专院校	
	单位所在地	浙江省 杭州市 西湖区	组织机构代码	12100000470095016Q	
	通信地址	浙江省杭州市西湖区余杭塘路866号	邮政编码	310058	
	银行账号	19042201040000014	法定代表人姓名	吴朝晖	
	单位开户名称	浙江大学	汇入地点	浙江省 杭州市	
	开户银行（全称）	中国农业银行杭州市浙大支行紫金港分理处	银行机构代码	103331004223	
推荐单位	单位名称	浙江省科学技术厅	推荐单位性质	□部门■地方□行业协会□产业技术创新战略联盟□其他	
项目负责人	姓 名	张丰	性 别	□男 ■女	出生日期 1977-02-04
	证件类型	身份证	证件号码	420111197702044062	
	所在单位	浙江大学			
	最高学位	■博士□硕士□学士□其他			

任务书签署

甲乙双方根据《国务院关于改进加强中央财政科研项目和资金管理的若干意见》（国发〔2014〕11 号）、《国务院印发关于深化中央财政科技计划（专项、基金）管理改革方案的通知》（国发〔2014〕64 号）、《国务院关于优化科研管理提升科研绩效若干措施的通知》（国发〔2018〕25 号）、《科技部 财政部关于印发<国家重点研发计划管理暂行办法>的通知》（国科发资〔2017〕152 号）、《财政部 科技部关于印发<国家重点研发计划资金管理办法>的通知》（财科教〔2016〕113 号）、《科技部财政部关于印发<中央财政科技计划（专项、基金等）监督工作暂行规定>的通知》（国科发政〔2015〕471 号）等有关文件规定，以及有关法律、政策和管理要求，依据项目立项通知，签署本任务书。

专业机构（甲方）：

法定代表人签字（签章）：

（公章）

年2020月2 1日

项目牵头承担单位（乙方）：

法定代表人签字（签章）：

（公章）

年　月　日
项目负责人签字（签章）：[signature] 2020年12月6日 推荐单位（盖章） 2020 年12 月8日

国家自然科学基金资助项目批准通知

（预算制项目）

张丰　　先生/女士：

根据《国家自然科学基金条例》、相关项目管理办法规定和专家评审意见，国家自然科学基金委员会（以下简称自然科学基金委）决定资助您申请的项目。项目批准号：42171412，项目名称：融合深度Koopman和过程理解的强非线性时空预测方法，直接费用：59.00万元，项目起止年月：2022年01月至 2025年 12月，有关项目的评审意见及修改意见附后。

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Predicting human mobility flows in cities using deep learning on satellite imagery

Received: 21 October 2024

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Yichen Xu[1], Song Gao[2], Qunying Huang[2], Aslıgül Göçmen[2], Qiang Zhu[3] & Feng Zhang[1,4]

Understanding the interaction between complex urban environments and human mobility flow patterns underpins adaptive transport systems, resilient communities, and sustainable urban developments, yet inter-regional origin-destination mobility flow information from traditional surveys are costly to update. The satellite imagery offers up-to-date information on urban sensing and opens avenues to examine urban morphology-mobility dynamics. This study develops a deep learning model, Imagery2Flow for predicting fine-grained human mobility flows in urban areas using 10 to 30-meter medium resolution satellite imagery in a timely and low-cost manner. Extensive experiments demonstrate good performance and flexible spatial-temporal generalizability on the top-10 largest metropolitan statistical areas of the United States. Through exploring the spatial heterogeneous effects, we investigate the urban factors (centrality and compactness) influencing human movement flow distributions, enhancing our comprehension of their interactions. The spatial transferability of Imagery2Flow helps reduce regional inequality by informing decisions in data-poor regions, learning from data-rich ones. Interestingly, the typologies of urban sprawl can help explain the cross-city model generalization capability. The temporal transferability proves that human dynamics of cities and the process of urbanization can be well captured from the observed built environment by remote sensing.

Cities are complex adaptive systems of spatial networks with vitality generated from continuous human activities and human-environment interactions. Human mobility, as a central component of human activities[1–3], reflects the flow of people within and between cities, and plays an important role in transportation management[4–7], urban planning[8–10], infectious disease modeling[11–14], disaster response[15–18], and energy production and consumption[19–21], thereby promoting policies to make cities resilient and sustainable[22,23].

For more than a century, researchers have proposed various models to model human mobility and infer the amount of human movement flows between locations[24–26]. These models can be classified into two categories based on their approaches: (1) mechanistic methods and (2) machine learning methods[27]. Mechanistic methods summarize the human movement process into the interaction mechanism between variables (e.g., population and distance) from the perspective of statistical physics, represented by three popular models at the collective scale: Gravity Model[1,28], Intervening Opportunities Model[29–31], and Radiation Model[32]. They mostly rely on probabilistic or parametric fitting methods, which may oversimplify the human movement process and make it difficult to capture complex patterns in the data, thus limiting the accuracy of the model. In recent years, with the rapid increase in urban population, human movements and spatial

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RESEARCH ARTICLE

TBSI: a Transformer-based spatial learned index for efficient construction and query

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ABSTRACT

The exponential growth of geographic data reveals limitations in traditional spatial indices. Spatial learned indices that incorporate machine learning models have been proposed to enhance index performance. However, due to the considerable overhead of fine-grained data partitioning and the complexity of hierarchical model structures, existing spatial learned indices still exhibit bottlenecks in index construction and query processing. To address the aforementioned issues, we propose TBSI, an in-memory Transformer-based spatial learned index with an end-to-end structure. TBSI employs an enhanced quadtree to optimize data partitioning and utilizes a Transformer-based position prediction model to manage each data partition, preserving a simple yet effective index structure. TBSI exhibits superior performance in both index construction and query processing. We also design spatial query algorithms based on a filtering-refinement mechanism and data update algorithms based on buffers and flag arrays to support efficient query processing and index maintenance. Extensive experiments on real-world and synthetic datasets demonstrated that, compared to baselines, TBSI achieved up to 23.4 times speedup in build time, up to 24.3 times reduction in index size, up to 5.9 times improvement in range queries, and up to 4.5 times improvement in *k*NN queries. Also, TBSI exhibited robust adaptability to dynamic data updates.

ARTICLE HISTORY
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KEYWORDS
Spatial database; spatial learned index; Transformer; index construction; spatial query

1. Introduction

The rapid growth of data acquisition technologies has facilitated the generation and utilization of multimodal geographic data, including remote sensing imagery, taxi trajectory, and social media data (Tian *et al.* 2022). While these data sources provide abundant research samples, their maintenance poses significant challenges (Ma *et al.* 2015). Spatial indexing technologies are widely employed for the organization and

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RESEARCH ARTICLE

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Dynamic mode decomposition and short-time prediction of $PM_{2.5}$ using the graph Neural Koopman network

Yuhan Yu[a,b], Hongye Zhou[a,c], Bo Huang[d], Feng Zhang[a,b] and Bin Wang[a,b]

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ABSTRACT

Analyzing and accurately predicting the spatiotemporal dynamics of $PM_{2.5}$ remain challenging. The existing spatiotemporal prediction approaches are associated with high model complexity and limited interpretability. Conventional methods combining Koopman theory and deep learning often neglect spatial correlations in spatiotemporal data. This study used the hourly $PM_{2.5}$ dataset of the Beijing-Tianjin-Hebei region to reveal its spatiotemporal hierarchy using Koopman mode decomposition to identify the key dynamic modes. Furthermore, a Spatial Physics Constrained Learning (SPCL) model utilizing a graph representation learning method was proposed to combine the graph topological information of the $PM_{2.5}$ spatial features with the Koopman feature function. The results showed that $PM_{2.5}$ has growth, decay, and oscillation modes as well as daily, weekly, monthly, and yearly periods. SPCL achieved mean absolute error, root mean square error (RMSE), correlation *r*, and index of agreement values of 9.678, 13.922, 0.864, and 0.921, respectively. The average RMSE at 12 h improved by 16.1%, 12.7%, 0.9%, and 3.5% compared with using Long short-term Memory, Graph Convolutional Networks and Long Short-Term Memory Networks, Spatio-Temporal Graph Convolutional Networks, and Dynamic Spatiotemporal Graph Convolution Network, respectively. By discretizing the neural network hidden layers, the explanatory key of $PM_{2.5}$ modes was elucidated, which demonstrated enhanced stability.

ARTICLE HISTORY
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KEYWORDS
Spatiotemporal prediction; deep Koopman; physics-constrained learning framework; Koopman pattern decomposition; $PM_{2.5}$

1. Introduction

Air pollutants, particularly particulate matter ($PM_{2.5}$), have become a major societal concern, garnering widespread attention owing to rapid industrialization and urbanization. The increase in $PM_{2.5}$ concentrations is closely linked to premature deaths related to respiratory and cardiovascular diseases (Pope 2000). The chaotic nature of changes in pollutant concentrations (Tang *et al.* 2022) indicates that the variation in pollutant concentration exhibits nonlinear dynamic characteristics. Thus, understanding the

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