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Additional Information

Intelligent and Energy-Efficient Data Prioritization in Green Smart Cities: Current Challenges and Future Directions

¹Khan Muhammad, ²Jaime Lloret, ¹Sung Wook Baik*

¹Intelligent Media Laboratory, Digital Contents Research Institute, Sejong University, Seoul, Republic of Korea

²Instituto de Investigacion para la Gestion Integrada de Zonas Costeras, Universitat Politecnica de Valencia, Spain

Abstract

The excessive use of digital devices such as cameras and smartphones in smart cities has produced huge data repositories that require automatic tools for efficient browsing, searching, and management. Data prioritization (DP) is a technique that produces a condensed form of the original data by analyzing its contents. Current DP studies are either concerned with data collected through stable capturing devices or focused on prioritization of data of a certain type such as surveillance, sports, or industry. This necessitates the need for DP tools that intelligently and cost-effectively prioritizes large variety of data for detecting abnormal events, and hence effectively manages them, thereby making the current smart cities greener. In this paper, we first carried out an in-depth investigation on the recent approaches and trends of DP for data of different nature, genre, and domain of two decades in green smart cities. Next, we proposed an energy-efficient DP framework by intelligent integration of Internet of things, artificial intelligence, and big data analytics. Experimental evaluation on real-world surveillance data verified the energy-efficiency and applicability of this framework in green smart cities. Finally, this article highlights the key challenges of DP, its future requirements, and propositions for integration into green smart cities.

Keywords

Green Smart Cities, Internet of Things, Data Prioritization, Surveillance Networks, and Energy-Efficiency

1. Introduction

The recent advancements in data capturing devices for smart cities have produced huge repositories whose management, searching, browsing, and indexing is a challenging issue. The major sources of this massive volume of data are consumer videos and surveillance networks.

The important contents from such data can be extracted using data prioritization (DP), which is an effective mechanism for producing a condensed form of huge data that have numerous applications in surveillance, medical, entertainment, sports, and industry. Among the two main sources of data, consumer DP is difficult, tedious, and time consuming due to the diversity in its contents and issues that occur during its acquisition under un-controlled conditions, which includes clutter, irregular lighting, poor quality sound track, and large capturing device motion. Besides, there are several other reasons that make consumer DP comparatively more challenging such as: 1) text features-oriented DP schemes are not suitable for consumer data due to lack of embedded text like subtitles and text captions, 2) lack of domain-specific knowledge for guiding DP systems, 3) in special cases, consumer videos usually consist of one long shot with challenging conditions like clutter, occlusions, uneven lighting, and complicated motions of several objects and camera, 4) a mixed sound track is produced due to several sources of sound at the background which makes it difficult to extract semantically important audio segments, and 5) difficulty in assessing the users' satisfaction with generated summaries using DP. People waste so much time in browsing through such large repositories of data generated in smart cities for desired contents. Thus, it is important to explore DP frameworks that would produce semantically good summaries, satisfying the requirements of consumers, hence increasing the efficiency of smart cities.

The second major source of data is multimedia surveillance networks; it consists of smart visual sensors for continuously recording images, thus, generating a huge amount of redundant visual data. Previous studies of surveillance networks have indicated that most of the captured data within a smart city are not important and transmitting them is not feasible due to energy and

bandwidth constraints. Besides, analyzing such huge amount of data in order to find important events for decision making is a rigorous and time consuming task. Furthermore, prioritization of data captured from multiple views with significant overlapping and redundancy (e.g. multi-view videos) in smart cities is more challenging compared to data collected from a single-view. Therefore, data analysis techniques need to be applied to filter and store important data for future use.

Considering these challenges, a green approach for intelligent data collection and prioritization is urgently required in smart cities to help it become greener [1]. These approaches can help in the selection of suitable view for sensing visual data in multi-viewed surveillance that consists of multiple sensors connected via Internet of things (IoT) infrastructure. Furthermore, data of interest will be processed in real-time; this will facilitate surveillance decision makers, and hence produce cost-effective services for green smart cities. To achieve these goals, we propose an energy-efficient and intelligent DP framework for a smart city. The major contributions of this work are highlighted as follows:

1. We first investigate the current approaches and trends of DP for data of different nature, genre, and domain of two decades and discussed its possible application in green smart cities.
2. We proposed an intelligent and energy-efficient framework of smart city by integrating IoT, DP, AI, and big data analytics, which will enable it to prioritize data captured from different environments in a cost-effective way, and consequently contribute to greener smart cities.
3. We conducted experiments on data captured by real surveillance cameras and evaluated its performance for adoptability, therefore providing a proof-of-concept to the research community of green smart cities.
4. We highlighted the key challenges of DP, followed by its future requirements with solutions, and prospects for future research in green smart cities.

The rest of the paper is organized as follows: Section 2 summarizes the recent trends for DP for

the last two decades. Section 3 presents the details of our framework for green smart city with experimental evaluation and discussion. Section 4 highlights the major challenges of DP and prospective requirements. Section 5 presents future research directions for effective integration of DP to green smart cities. Section 6 concludes the paper by presenting the key findings of this work.

2. Recent Trends for Data Prioritization

In this section, we highlight the trend of DP techniques, ranging from conventional low-level features to the recent frameworks of convolutional neural networks (CNNs). Our focus will be on video data because it is generated at an exponential rate and can play a vital role in improving the services of green smart cities. DP tends to identify pertinent contents in data and generate a concise representation that can either be in the form of key frames, showing the salient frames in a video or video skims. Video abstracts can either be generated manually or automatically. The former approach seems less feasible due to the current massive volume of video data generated in smart cities, thus, automatic DP methods are preferred for generating summaries, saving manpower and other constrained resources.

The existing literature uses two features for prioritization: Low-level features like color, shape, moments, motion and visual attention models based DP whose prioritized contents are in accordance with human perception. The pioneer work on visual attention was presented by Ma *et al.* Following this work, many visual attention driven DP methods were presented for different domains such as surveillance, industry, medical, and agriculture [2], indicating that DP methods based on visual attention model generate semantically relevant summaries. However, such methods are comparatively expensive in terms of computation; they also ignore the active responses of users, making them less efficient in fulfilling users' preferences. To tackle this issue, electroencephalography brain signals of viewers are considered for analysis of videos during its prioritization. For instance, Mehmood *et al.*, [3] combined visual attention, aural attention, and neuronal attention models through inter and intra-

modality fusion mechanism in divide-and-conquer fashion for personalized DP. Summarizing the literature of DP for two decades,

four main classes can be found as illustrated in Table 1.

Class Name	1. Cluster based DP	2. Visual attention based DP	3. Event based DP	4. Multi-modality based DP
Key Approaches	Similar activity, K-means, partitioning, and spectral based methods	Motion, texture, and multi-scale contrast saliency based methods	General event and deep features based event-assisted methods	Visual and audio features based, and hybrid methods
Main Steps	Feature extraction from input data, clustering, and important data selection	Salient contents detection from input data, followed by important data selection	Object detection and tracking in input data, abnormal events detection, and prioritization	Feature extraction from input data, their fusion, attention curve generation, and prioritization
Key Characteristics and Limitations	-Simple and concise Suitable for data such as news and documentary videos -Low-level features cannot represent diverse visual contents captured in green smart cities effectively -Has semantic gap problem, failing to fulfill the varying user's requirements	-Use visual attention model to extract summaries closer to human perception -Mainly applicable to medical and surveillance domains -Computational visual attention models may not adequately represent human attention	-Detect event and then prioritizes the data, thus the generated summaries are more closer to human semantics -Mainly suitable for sports and surveillance domain. -Computationally expensive for complex events such as goal and event detection in crowded scenes of green smart cities	-Consider multiple modalities for more effective DP -Mainly suitable for entertainment and sports domains -Fusion of multiple modalities is difficult, considering users' preferences and reliability of each modality in IoT-assisted green smart cities

Table 1. Classification of DP methods of the last two decades (1998-2018)

The DP methods discussed so far are based on hand-crafted features which is a tedious task and lack discriminative feature for intelligent DP. In this context, rich features from CNNs can be combined with aural, visual, and neuronal attention models for efficient DP. For instance, Fei *et al.*, [4] presented memorable and rich DP method for selecting important contents using entropy and memorability scores predicted by a modified AlexNet model. Their model can produce summaries by considering the diversity of captured contents and human perception.

3. Proposed Data Prioritization Framework

In smart cities, a significant number of sensing devices collect data from various sources. Visual sensors are one of the major visual data collection sources, producing a huge amount of data [5]. The energy and bandwidth constraints limit the processing of such huge sized data, thus, only prioritized data needs to be stored for case management and analysis. Also, searching through large volumes of data for required information is time consuming and inefficient. To address these issues, we propose a data prioritization framework for autonomous collection of visual data. This framework processes multiple streams from visual sensors for intelligent selection of suitable view for

prioritization in IoT-assisted multi-viewed surveillance environment. The smart sensors are trained to prioritize data, detect important events, and autonomously inform the concerned department about the detected event. Such distributed processing of huge real-time data facilitate their efficient storage, management, retrieval, and analysis as well as minimize the energy and bandwidth requirements, thus helping smart cities to become greener. The overview of our framework is presented in Figure 1.

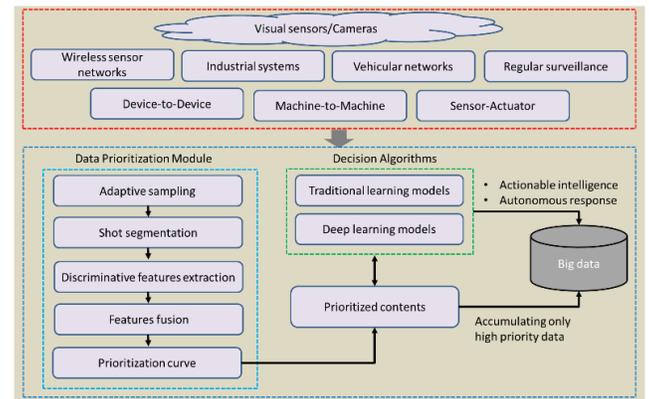


Figure 1. Overview of the proposed architecture for intelligent data prioritization

The proposed system was experimentally tested on a Core i5-3570 CPU @ 3.40 GHz with MATLAB R2018a based energy consumption to

highlight its performance for data prioritization in green smart cities. The energy consumption is evaluated for five videos collected from real surveillance environment. The experimental specification is similar to the report by Irgan *et al.* [6], where 88.48 μJ energy was required for a packet transmission of which a frame consists of 4219 packets. To this end, the total consumed energy can be represented by $E_t = N \times e_p$ where, e_p is the energy required for transmitting one data packet and N refers to the total number of packets in a given frame. The experimental results are presented in Figure 2, showing the reduction in energy consumption. Furthermore, the proposed system enables the surveillance analyst to analyze only the important prioritized data, thereby improving the decision making process and reducing the analyst's efforts. These features make this system more suitable for energy-efficient data sensing and processing in green IoT environments.

Recent studies verify that both academia and industry have shown significant interest in green

smart cities, with focus on their different aspects such as DP, security, interoperability, and communication [1, 7, 8]. Table 2 presents a summary of recent projects from different regions of the world such as Asia, Europe, and North America related to the development of green smart cities.

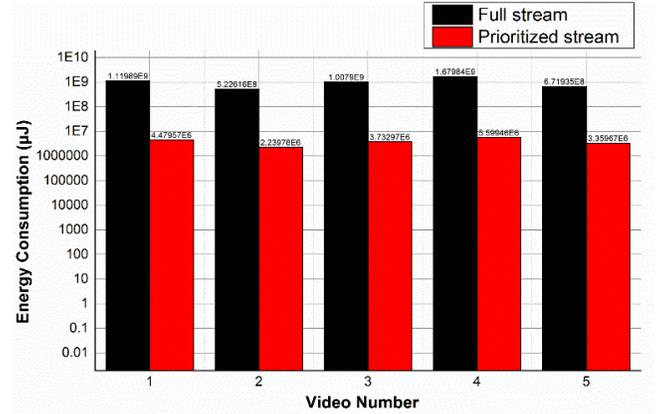


Figure 2. Energy consumption for transmission of only key frames vs energy required for disseminating the full stream.

Project Name and Country	Funding	Duration	Goals	Main Partners
REPLICATE from Spain	European Commission	2016~2021	Increasing resource and energy efficiency, improving the sustainability of urban transport, and reducing greenhouse gas emissions in urban areas	38 partners including 7 public organizations, 24 multi-sectoral companies, and 5 universities
Smart Seoul from Republic of Korea	Korea Government	2015~2019	Intelligent data prioritization and autonomous response generation, abnormal events detection, smart building energy management, exchange of information via different devices and communication sources.	National Research Foundation of Korea, Seoul metropolitan government, universities, and other regional agencies
Greener Busan from Republic of Korea	Korea Government	2014~2020	Smart missing-child prevention service, smart parking, drones, street light, and energy management.	Busan government, Cisco, ETRI, KETI, SK telecom, and KT
Fujisawa Sustainable Smart Town from Japan	Japanese Energy and Government Bodies	2014~2020	Reduction in energy costs, bicycle sharing, and smart healthcare.	19 companies and 1 association including Fujisawa SST management company and Panasonic corporation
Green Vision from United States	State and federal funding	2007~2022	A total of 10 main goals including energy reduction by 50%, zero-emission lighting, and 100% energy from renewable sources	Different universities, private companies, and regional agencies

Table 2. Summary of world-wide latest projects and initiatives for green smart cities

4. Current Major Challenges and Requirements

Both academia and industry have shown interest by investing significant funding and researching on different aspects of green smart cities. For instance, a green approach for minimizing the amount of data was exploited in [9]. Similarly, a mechanism to integrate big data analytics with electric vehicles in green smart cities is presented

in [10]. To integrate cloud computing and sensors for big data in green cities, Zhu *et al.*[11] proposed three sensor-cloud services for sensing, transmitting, and sharing, respectively. An IoT-assisted smart metering system for smart cities was presented in [12]. To cover the energy management aspect of IoT-assisted smart cities, Ejaz *et al.*[13] presented an efficient optimization and scheduling framework. The green industrial

networking aspect was investigated in [14]. Last but not the least, a perspective of 5G technologies with soft and green themes was explored in [15]. Intelligent and cost-effective DP is one of the preferred embodiments of smart cities, which can play a vital role in making the current smart cities greener. To date, attempts have been made to deal with data of different domains such as surveillance, sports, consumer, broadcasting platforms, and news. Despite the accepted

performance for prioritization, there are still issues and challenges that limit the effectiveness of DP methods for generating summaries that could fully satisfy the requirements of users and green smart cities. After an extensive literature review, we found several key features, their applications and advantages, major research challenges, and requirements of future green smart cities, which are presented in Table 3.

Feature	Applications and advantages	Research challenges	Major requirements
1.Data prioritization	Smart surveillance, intelligent transportation, healthcare, disaster management, and real-time observation of the ongoing activities in smart cities, helping them further greener.	-Diversity of data captured in smart cities -Overlapping and redundancy in captured data from multiple views -Real-time prioritization of data and events detection -Complexity and lack of end-to-end deep learning based DP architectures and standard evaluation tools	-Energy-efficient and intelligent prioritization for data of different domains -Considering both inter- and intra-view correlation in DP for multi-view data -Minimization of semantic gap (e.g., by integration of deep learning and big data) -Personalized DP and intelligent multi-modality information fusion for DP
2.Security and privacy	Healthcare, smart schools, smart surveillance, intelligent transportation, logistics, smart meters, and protection of user's data in the network and deployment of attack-free services	- User's anonymization in smart city network for different services - Lack of standard security solutions with no compromise on data integrity - Secure integration of edge and cloud services and their deployment - On-time detection of indoor and outdoor security threats	- Cost-effective and strong encryption tools - Intelligent identification of black holes in IoT environment that serves as weak entry points for malicious users - Energy-efficient data de-identification mechanisms for ensuring user's privacy
3.Data dissemination	Smart surveillance, intelligent transportation, smart industry, improved and on-time transmission of required data to concerned parties/devices and large variety of applications in green smart cities subject to low-cost communication	-Reliable data transmission -Energy-efficiency -Secure data dissemination -Prolonging the battery life of IoT devices	-Intelligent spectrum sensing algorithms for reliable and cost-effective data transmission and dissemination solutions -Identification of communication points, leading to data breaches -Improvement in IoT devices and wireless technologies for extending the battery lifetime and ensuring low-cost communication
4.Data reconstruction	Healthcare, improvement in event detection, and decision making	- Quality assurance of reconstructed data - Computational complexity	-Intelligent reconstruction schemes -Cost-effective solutions for reconstruction
5.Big data	Healthcare, intelligent transportation, actionable intelligence, improved performance by processing the filtered data provided by "data prioritization" feature.	-Lack of intelligent tools for processing the gigantic volume of data -Ensuring user's privacy during data acquisition and its cost-effective indexing -Fast retrieval algorithms for desired contents extraction	-Edge and cloud assisted big data processing centers -AI-assisted intelligent tools for extraction of actionable intelligence -Awareness to public about careful utilization of IoT network in smart cities

Table 3. Main features of green smart cities, their challenges, requirements, and future research propositions

5. Recommendations for Future Research

Considering the aforementioned major challenges in Table 3 encountered by DP community, extensive work is required from DP industry and academia in the following areas to contribute to greener smart cities:

- 1) *Fog computing-assisted DP*: Fog computing is a new paradigm for extending the cloud computing to the edge of the network, providing high mobility, low latency, and vast geographical coverage of large number of nodes. It has several potential applications in

IoT based systems, real-time computing systems, energy aware computing, latency sensitivity, and mobile applications .However, it is still new and needs strong groundwork for adoption in DP community of green smart cities in terms of practical feasibility, cost-effectiveness, efficiency, and ease in deployment as an alternate to current ubiquitous cloud systems. In addition, mobile cloud-assisted architectures can also be investigated for DP.

- 2) *Solving DP as multi-objective optimization problem*: To cover all important contents in the collected data with minimal redundancy and computationally efficiency, DP should be considered as a multi-objective optimization problem. Using this approach, important events can be detected more effectively, while considering the processing and power constraints of IoT devices in green smart cities.
- 3) *Benchmarking datasets*: To make DP in green smart cities an interesting topic of attraction for researchers, it is important to collect specific large DP datasets with ground-truth just like other communities (e.g., ImageNet for image classification). Such datasets can be used for benchmarking as well as hosting different competitions in attempt to improve the performance of DP for green smart cities.
- 4) *Light-weight convolutional neural networks (CNNs) for DP*: Recently, CNNs have achieved state-of-the-art performance in data classification and other computer vision tasks. However, their major concerns are high memory and computational requirements. Therefore, energy-friendly and computationally efficient CNN architectures need to be explored for DP, which can further help the current smart cities to be greener.
- 5) *Universal DP evaluation and personalization*: The current DP community heavily relies on subjective evaluation mechanism. Thus, further research is required to devise a universal evaluation mechanism which can automatically measure the performance of DP methods from different perspectives. Another research direction is to explore personalized data prioritization for smart phones, by considering their constrained resources, as they are integral components of green smart cities.

6. Conclusion

In this paper, we investigated the performance of state-of-the-art data prioritization schemes for the last two decades. We covered DP methods which use clustering, visual attention models, important events, and multi-modalities for prioritization and analyzed CNNs for data summarization in smart cities. We also considered DP methods from

different domains such as surveillance, industry, sports, and medical, which can be collected for different smart services of green smart cities. Following the knowledge gained from reviewed literature, we proposed an energy-efficient framework of green smart city by intelligent integration of IoT, DP, AI, and big data analytics. We conducted experiments on surveillance data captured from real scenarios and verified the energy-efficiency and applicability of our framework for deployment in green smart cities. Finally, we overviewed the strengths and weaknesses of DP methods and highlighted the major challenges and recommendations for future research in order to advance the concerned smart services and make them greener from different perspectives in smart cities.

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Khan Muhammad [S'16] (khan.muhammad@ieee.org) is a research associate at IM Lab, Digital Contents Research Institute, Sejong University, South Korea. His research interests include information security, video summarization, computer vision, and video surveillance. He has authored over 40 papers in peer-reviewed international journals such as *IEEE TII* and *IEEE TSMC-Systems* and is a reviewer of over 30 *SCI/SCIE* journals including *IEEE COMMAG*, *Network*, *IoT*, *TIP*, *TII*, *TCYB* and *Access*. He is a member of the *ACM*.

Jaime Lloret [M'07, SM'10] (jlloret@dcom.upv.es) is an associate professor at Politechnic University of Valencia, Spain. He was Internet Technical Committee Chair during 2014–2015 and current Chair of IEEE 1907.1. He is the director of the Research Institute IGIC and head of the Innovation Group EITACURTE. He is co-Editor-in-Chief of *Ad Hoc and Sensor Wireless Networks* and Editor-in-Chief *Network Protocols and Algorithms*. He has been General Chair of 36 international workshops and conferences.

Sung Wook Baik [M'16] (sbaik@sejong.ac.kr) received the B.S, MS, and PhD degree in computer science from Seoul National University, Korea, Northern Illinois University, USA and George Mason University, USA in 1987, 1992, and 1999, respectively. He is currently a Full Professor and Head of Intelligent Media Laboratory at Sejong University, South Korea and active reviewer of several reputed journals. His research interests include computer vision, multimedia, pattern recognition, machine learning, and data mining.