Applications of big data and communications to sustainable development of smart cities

A V Gayer, Y S Chernyshova and I B Mamai1

Federal Center of Theoretical and Applied Sociology of Russian Academy of Sciences, 24/35, Krzhizhanovsky Street, Moscow, 117218, Russia

1E-mail: ibmamai@mail.ru

Abstract. The formation of a smart city is a dynamic process that involves the implementation of systemic steps that transform the city into a comfortable environment for living. Smart cities are evolving on the basis of a flexible telecommunications architecture for IoT devices. Existing sustainability technologies require a large amount of computing power to process IoT data. For effective detection and localization of dysfunctions of complex socio-technical systems of smart cities, it is proposed to use an approach based on a parametric representation of objects of interest. In order to eliminate the influence of the variability of the Internet of Things on the classification accuracy, it is proposed to use a combination of optimality principles, taking into account the parameters of energy consumption, processor and memory usage.

1. Introduction

Modern megacities have complex infrastructures that need to be effectively developed, modernized and adapted to the needs of society. A smart city is the most effective concept of such management, which provides for the reorganization of all spheres of the city's life through the creation and implementation of modern information telecommunication technologies. The implementation of the concept of a smart city implies the creation of effective management mechanisms, intelligent systems with elements of diagnostics, service, control, processing of big data, security and cybersecurity.

The world's leading megacities are implementing various projects, collectively called “Smart City”, to improve the quality of life, safety, energy consumption, environmental control and economic growth. The urban population is constantly growing, the effective management of megacities creates new challenges for the implementation of digital technologies and intelligent systems. Information and communication technologies are used to improve the quality, productivity and interactivity in the functioning of city services, in order to reduce costs and resource consumption, to establish socio-communication links between citizens and government structures [1].

The need for technological, economic and environmental changes raises interest in the formation of the Smart City project portfolio, which takes into account climate change as part of the digitalization of the economy. In [2, 3], a number of projects are considered aimed at increasing innovation and investment in the development of ICT to improve the quality of public services and improve the standard of living of residents of megacities. Projects for the formation of digital telecommunication networks, which have already been introduced into the general infrastructure, provide the functionality of various areas of the city's life and its effective management. Currently, there is a gap in studies of the features of the implementation of innovative smart city projects in the world's megacities in order to determine...
an effective architecture and approaches to modernizing digital information and telecommunication networks of big data.

2. A project-based approach to building a smart city

“Smart city” is a portfolio of projects, the implementation of which ensures the innovative development of all systems of a particular city. Such development is carried out on the basis of the integration of social, information and telecommunication technologies, taking into account the mentality of the inhabitants and the history of the city’s development. The projects of this class take into account that the city’s infrastructure consists of a number of subsystems: city information systems, educational institutions, libraries, medical institutions, power plants, industrial enterprises, engineering networks, video surveillance, environmental monitoring, law enforcement agencies, etc. The purpose of the Smart City projects is to improve the quality of life through the use of the latest innovative information and telecommunication technologies for processing big data, increasing the efficiency of services and economic growth.

There are many strategies for turning a city into a smart city, but the main aspect is the formation of modern telecommunication technologies and networks that ensure the integration of information into call centers, based on the use of cloud and GRID technologies, the creation of systems for accumulating, storing and processing information, statistical analysis, and control of various parameters. Many modern cities differ significantly in the level of development of the network telecommunications infrastructure, and as a result, there is an urgent need for its development. First of all, from the point of view of the compatibility of such networks, the level of their intelligence and scalability, the efficiency of resource use, and reducing the negative impact on the environment.

Telecommunication networks for processing big data provide communication, security, accuracy of information transfer between various institutions, cloud providers, call centers, sensor systems, devices and consumers.

The basis of telecommunication networks for processing big data in a “smart city” is a fiber-optic network located along the perimeter with access via wireless technologies [4]. It provides the ability to connect with each other and transfer critical data for a large number of nodes. In addition, it can include: multiple mobile networks, satellite communication systems, fiber optic networks, wireless mesh network of homes and offices, etc.

The cloud computing framework provides efficient optimization when handling large datasets generated by thousands of sensors throughout the city. Cloud computing provides the ability to remotely process large amounts of data or use licensed software products over the Internet. The Internet of Things allows a huge number of devices to be connected using smart sensors, satellite communications and GPS navigation. These technologies are evolving towards the integration of resources and capabilities of human intelligence, collective intelligence, artificial intelligence within a single city. Smart city operates in an efficient combination of digital telecommunication networks, smart sensors and modern software.

Each functional link of the city is part of a complex portfolio of smart city projects, the implementation of which ensures effective planning of technological processes, analysis of the operating conditions, monitoring, diagnostics and correction of results. This approach contributes to the creation of effective mechanisms for managing engineering networks, the implementation of the concept of e-government, etc. The formation of a smart city is a dynamic process that involves the implementation of sequential steps that turn the city into a comfortable environment for living, adapted to new realities and capable of responding to new challenges.

The use of intelligent software systems contributes to efficient transport management, roadway monitoring sensors and smart parking applications [5, 6]. The sensor network uses wired and wireless networks to communicate with each other. Sensors provide control of physical quantities, environmental conditions (temperature, sound, vibration, pollutants, etc.). Smart sensors provide control of smart grids for the supply of electricity, water and gas [7, 8]. Urban "smart infrastructures" are formed on the basis of modular technologies [9, 10]. Sensors, meters, and various peripheral devices that transmit
information to an intelligent big data center at certain intervals or continuously are important components of intelligent systems "Smart City". Big data centers enable efficient urban planning and smart utilities that benefit low- and middle-income populations. Smart services are evolving around flexible telecommunications architecture, open platforms, and monitoring of Internet of Things (IoT) devices.

3. Intelligent technologies for sustainable development

Existing sustainable development technologies that use IoT data processing algorithms require a large amount of computing resources [11]. In addition, they allow detecting only the presence of a certain type of state of stability of ecosystems of megacities, being unable to distinguish one type from another [12]. In existing systems, the collection and analysis of the obtained data is divided into two different stages and, therefore, real-time detection is not possible. A client-server architecture is used, where the client is a mobile application that collects data and then sends it to the server. The program on the server performs segmentation to distinguish the object of interest of the ecosystem from its environment using threshold binarization and the maximum entropy method. The segmented area is then filtered through a median filter to remove noise. Finally, the decision is made by comparing the highlighted areas with the smart city scene using the standard deviation.

Despite the fact that stationary systems provide good performance and a high level of accuracy, they are not suitable for fast real-time analysis [13]. For example, the thresholding method captures data and segmentation. An artificial bee colony algorithm is used to determine the optimal threshold value [14]. Area classification is carried out using artificial neural networks. The considered approaches provide a reliable classification with a high degree of accuracy. Nevertheless, the performance of the methods significantly depends on the quality of the initial data of the smart city information systems and the results of the segmentation stage. The AdaBoost algorithm is used to combine the results of visual assessment and the features of the object of interest, but despite its good performance, it has high computational costs.

Modern research in the field of analysis of IoT devices in smart cities consists in processing big data of megacities, obtained in the absence of any restrictions on the conditions for observing the state of the ecosystem [15, 16]. Two independent approaches can be used together to improve the computational efficiency of algorithms for classifying information with a high dimension of the feature space and a large number of classes. According to the first of them, there is a selection of a relatively small number of features. The most efficient feature selection is characterized by algorithms based on the theory of approximate sets, in which the best approximation of the initial description of information is sought using as few features as possible [17]. The second approach includes methods of approximate search for the nearest neighbor, for example, various variants of k-d trees, ordering permutations, local hashing of objects of interest in a smart city.

An increasing number of researchers associate the solution of such applied problems with the theory of soft computing. At the same time, the emphasis on practical application naturally leads to the refinement of the fundamental concepts of these theories. For example, the use of the theory of granular computations and ternary solutions to improve the efficiency of information systems in megacities using neural networks [18, 19]. The neural network accepts data as input and implements several convolutions as the first hidden layers, and the coefficients of the convolution kernels are trained. The currently used methods to achieve a high level of classification quality use a large number of neurons, which ultimately complicates the use of classifiers in real-time systems of smart cities.

For effective detection and localization of dysfunctions of complex socio-technical systems of smart cities, it is proposed to use an approach based on a parametric representation of objects of interest. The method of generating stable descriptions of objects of interest is used to identify and compare arbitrary objects. However, its application to problems of detection and classification in big streams of heterogeneous data is an original and insufficiently studied approach. The choice of this method for solving problems of detection and classification is also justified by the wide possibilities of parameterization of this approach. This will ensure the reliability and robustness of detection and
classification, as well as high performance, which is important given the limited computing resources of mobile IoT devices. Applied to big data analysis of IoT smart cities. It is proposed to represent objects of interest in the form of a feature tree \( P^O \) with the possibility of branching at nodes \( \overline{O} \). In order to eliminate the influence of IoT variability on the classification accuracy, the problem of maximizing a combination of optimality principles is solved. The problem is solved, taking into account the multisets of parameters \( L \) of energy consumption \( N \), processor \( W \) and memory usage \( M \):

\[
\overline{L} = \{ < \ell \in L, LN = \overline{l}.N > | \forall \overline{l} \in \overline{L} (l.W = \overline{l}.W) \}; \\
\overline{O}_o = \{ < o \in O, N = \overline{o}.N > | \forall \overline{o} \in \overline{O}, \exists \overline{l} \in \overline{L}, \ell \in L \\
(\overline{o}.W = \overline{o}.W & o.M = \overline{l}.M & l.N = \overline{l}.N & l.M = \overline{o}.N) \}
\]

(1)

\[
Net(O, P^O, \overline{O}, \overline{P}, \overline{O}_p, \overline{P}_p) ; \\
NetL(L, P^L, \overline{L}, \overline{P}, L, P^O) ; \\
\overline{P}^O = \{ p \in \overline{P}_p | \exists o \in \overline{O}, p.ON = o.N \}.
\]

The accuracy score is weakly dependent on how well the objects of interest of the smart city ecosystem match in a certain range, and can change sharply when any of the matched objects moves away from its pair at a certain distance. Therefore, for the maximization problem, an estimate is also used that takes into account the distance between the matched objects of interest.

In order to increase the efficiency of classification in real time, various preprocessing methods are used: transformation of objects of interest; median filtering; averaging histogram; binarization; morphological analysis. Parallel implementation of these methods made it possible to reduce the computation time for processing big data and obtain objects of interest with improved characteristics after highlighting the smart city scene based on the optimality criteria. The proposed criteria for the optimality of detection and classification algorithms take into account the limited resources of mobile IoT devices. Generalization is used in the efficiency factor of the classifier: harmonic mean of accuracy and sensitivity; consent criteria; robustness and information criteria. According to the developed criteria for each object, it is proposed to use a complex criterion that takes into account the distribution of the absolute deviation of the result obtained. This approach allows for a more adequate assessment of the classifier of a specific object on mobile IoT devices than using a constant threshold in existing information systems of megacities.

4. Conclusion

Information and telecommunication systems for processing big data are a key component of a smart city. When developing intelligent systems for analyzing big data in a smart city, it is necessary to take into account the specifics of the infrastructure. It is necessary to introduce innovative solutions of a mobile type in order to diagnose and predict sustainable development. Digital solutions of an intelligent decision support system for identifying and eliminating dysfunctions of the national environmental protection system in a megalopolis based on IoT devices of smart cities are proposed.

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References
[1] Tranos E and Ioannides Y 2020 Telematics and Informatics 55 101439
[2] Buuse D and Kolk A 2018 Technological Forecasting and Social Change 142 220-34
[3] Kramers A, Hojer M and Wangel J 2014 Environmental Modelling & Software 56 52-62
[4] Wang D, Zhou T and Wang M 2021 Technology in Society 64 101516
[5] Strzelecka A, Ulanicki B and Elelman R 2017 Procedia Engineering 186 609-16
[6] Pradhan R, Arvin M and Nair M 2021 Cities 115 103213
[7] Zahmatkesh H and Turjman F 2020 Sustainable Cities and Society 59 102139
[8] Sharma A, Sing P and Kumar Y 2020 Sustainable Cities and Society 61 102332
[9] Saadi M, Noor M and Imran A 2020 Sustainable Cities and Society 60 102266
[10] Sodhro A, Pirbhulal S and Luo Z 2019 Journal of Cleaner Production 220 1167-79
[11] Atitallah S, Driss M and Ghezala H 2020 Computer Science Review 38 100303
[12] Majumdar S, Subhani M and Zhu R 2020 Sustainable Cities and Society 64 102500
[13] Bibri S 2017 Sustainable Cities and Society 38 230-53
[14] Yousefi S, Derakhshan F and Karimipour H 2020 Computers & Electrical Engineering 86 106733
[15] Linde L, Sjodin D and Wincent J 2021 Technological Forecasting and Social Change 166 120614
[16] Hatuka T and Zur H 2020 Telematics and Informatics 55 101430
[17] Sharma S, Dua A and Prakash S 2017 Renewable and Sustainable Energy Reviews 82 3633-44
[18] Serrano E and Bajo J 2019 Future Generation Computer Systems 100 122-31
[19] Said O and Tolba A 2021 Sustainable Cities and Society 69 102830