Formalizing and securing relationships on multi-task metric learning for IoT-based smart cities

B I Savelyev, S V Solodov and D V Tropin
Federal Center of Theoretical and Applied Sociology of Russian Academy of Sciences, 24/35, Krzhizhanovsky Street, Moscow, 117218, Russia

Abstract. The use of modern information and communication technologies is an essential condition for the formation of the transport infrastructure of a smart city. Scientific and methodological approaches are developed to effectively monitor the transport infrastructure of a smart city based on multi-channel metric learning in the Internet of Things. The proposed solutions provide invariance to the type and nature of the movement of objects. The principles of technical implementation of the proposed method are substantiated using the characteristics of unmanned aerial vehicles of a smart city. Adaptive automatic switching of transport infrastructure monitoring channels is implemented in the form of a neural network analyzer software.

1. Introduction
The Internet of Things (IoT) is the interconnection of physical devices, vehicles, buildings and other items provided with electronics, software, sensors that allow these objects to collect and exchange data. The Internet of Things allows devices to be discovered or monitored remotely through existing network infrastructure, creating opportunities for direct integration of the physical world into a computer system, resulting in increased efficiency, accuracy, and economic benefits. When the Internet of Things is complemented by sensors and actuators, this technology becomes the basis for more general cyber-physical systems that also encompass smart city technologies such as smart grids, smart homes and smart transportation. Each item is uniquely identified through its embedded computing system, but is capable of interacting with the existing infrastructure of the Internet.

The Internet of Things is especially relevant for the development of transport infrastructure, since it provides systems for collecting and processing information in an automatic mode in order to increase the efficiency, reliability, sustainability and economy of the distribution of traffic flows. At the same time, it is necessary to achieve high reliability and accuracy of the analysis, under adverse weather conditions and the presence of interference of natural and artificial origin. The main technical means of solving telecommunication problems are radar means of a smart city. However, there are significant limitations to the effectiveness of existing radar facilities of a smart city based on direct electromagnetic contact with transport infrastructure objects [1, 2]:

- one-channel;
- insufficient range of action;
- operability only for moving infrastructure objects of the smart city.
Ground-based radar means of a smart city, based on the tangent method for determining the location of transport objects [3, 4], providing targeted multichannel, have insufficient range due to energy constraints. Removing the restrictions of the radio horizon is provided by means of monitoring devices of the Internet of things [5]. However, the existing telecommunication schemes for transmitting information are characterized by a significant time delay, which is unacceptable for highly dynamic transport systems of a smart city.

Therefore, it is relevant to search for methods and ways to ensure high-precision monitoring of the infrastructure of a smart city at the maximum ranges of the Internet of Things devices with a simultaneous increase in the target multichannel in the range of all possibilities of its effective application. At the same time, the use of the potential information capabilities of observation channels of various parts of the spectrum of electromagnetic waves [6] by means of their constructive and functional integration becomes of fundamental importance.

2. Radio engineering and telecommunication systems of a smart city

Modern information technologies cover all spheres of city life. Under their influence, there is a radical change in all processes in the city management system, they automate management processes, contribute to the effective development of management decisions, and make management more transparent. IoT technologies are increasingly being used in smart city telecommunication systems. They are a prerequisite for the development of smart cities. Together with the benefits from their use, the threat of their misuse for analyzing the transport infrastructure of a smart city increases.

In the ranges of the spectrum of electromagnetic waves used to analyze the transport infrastructure of a smart city, the limiting range of detection, measurement of coordinates and recognition of objects is determined by the line-of-sight range. In a radar channel, even in the presence of direct optical contact with objects of the transport infrastructure of a smart city, the maximum range of its observation is determined by the effective scattering surface.

Known methods of increasing the radio horizon when observing ground objects of a smart city are based on the use of telecommunication systems for transceiver devices [7, 8]. However, the application of this approach significantly increases the complexity and technical characteristics of the structure and, as a consequence, the cost of such systems. On the other hand, there are known ways to remove restrictions on the radio horizon through the use of unmanned aerial vehicles within a smart city [9]. However, the isolation of the aperture parts of the telecommunication channels does not allow realizing the potential possibilities of monitoring infrastructure objects in a dynamically changing environment over the entire depth of range.

In [10, 11], it is shown that the integration of observation channels of different parts of the spectrum of electromagnetic waves within the framework of a general information-measuring system is a powerful tool for increasing the reliability and accuracy of remote monitoring of transport objects of a smart city. In [12, 13], algorithms for multispectral information processing were obtained, taking into account the synchronization of partial spectral channels at different stages of observation of infrastructure objects (identification, estimation of coordinates, recognition). In [14, 15], a methodology was developed and options for constructive integration of partial spectral observation channels were considered to ensure mutually consistent work in space and time. However, the dependence of the potential capabilities of partial spectral channels in the optical range, which is associated with the state of the surface layer of the atmosphere (rain, dust and smoke obstacles, time of day), limits the range of their effective use when installing equipment on ground infrastructure facilities of a smart city, while the channels radio bands are practically devoid of this drawback.

3. Multitasking IoT metric learning

The main scientific and technical idea of the proposed approach to improve the efficiency of monitoring the infrastructure of smart cities based on the Internet of Things is to expand the range, target multichannel and remove restrictions on the nature and parameters of movement of transport infrastructure objects. It is proposed to use a combination of the advantages of high-potential
multichannel radio engineering systems and multitasking metric learning of IoT devices installed on unmanned aerial vehicles within an integrated complex. At the same time, the practical implementation is based on the constructive and functional integration of various technical solutions [16, 17]. The practical implementation of the method includes:

- the use of one or more spatial observation channels, which are formed by a phased antenna array in normal mode for multitasking metric training of unmanned aerial vehicles of a smart city;
- placement on an unmanned aerial vehicle of multispectral equipment for monitoring transport infrastructure objects of a smart city.

If multispectral monitoring equipment is placed on board an unmanned aerial vehicle, it is necessary to use special algorithms for solving location problems of identifying, evaluating coordinates and recognizing transport infrastructure objects. When integrating partial channels at the level of a smart city decision support system, it is proposed to use the following functionality as an optimality principle:

\[
F = \left( \sum_{i=1}^{N} \left( f^+ - f_i a_i \right)^2 \right)^{1/2},
\]

where \( a_i = (a_{i,1}, \ldots, a_{i,n}) \) is the vector of partial decisions, if \( a_i = 1 \) is the decision on the presence of a signal, made by the \( i \)-th channel of the Internet of Things; otherwise, the decision about the absence of a signal is made by the \( i \)-th channel of the Internet of Things; \( f_i \) is the weighting factor characterizing the information contribution of the \( i \)-th partial Internet of Things channel in identifying the observed object, and \( f^+ \) is the maximum value of the weighting factor.

The weighting factor is of a probabilistic nature:

\[
f_i = \ln \left( \frac{P_i^T (1 - P_i^F)}{P_i^F (1 - P_i^T)} \right),
\]

where \( P_i^T \) is the probability of correct detection in the \( i \)-th partial Internet of Things channel; \( P_i^F \) is the probability of false detection in the \( i \)-th partial IoT channel.

In case the multitasking metric learning consists of three channels: optical, infrared, radar. Then, the optimal value of the objective function (1) will be achieved in the case:

- favorable weather conditions \( a_1 = 0 \);
- meteorological precipitation \( a_2 = 0 \);
- night period \( a_3 = 0 \).

These ratios reflect the fact that at small distances corresponding to the flight altitudes of unmanned aerial vehicles, the observation channels of ground objects can be differentiated in terms of efficiency with the subsequent disconnection of ineffective ones. It should be noted that the proposed methodology applies to algorithms for estimating coordinates and recognizing objects in the transport infrastructure of a smart city.

Adaptive automatic switching of observation channels is implemented in the form of software for a neural network analyzer of smart city infrastructure. The analyzer uses information from controllers that collect and process information.

Processor means are used as controllers. The amount of memory and data is determined by the type of controller. Microcontrollers were used to create prototypes of such sensors. Microcontrollers were programmed using the functions of the C and C++ languages in the PlatformIO environment. In addition
to using traditional compilation tools, the PlatformIO project provides an integrated development environment (IDE) [18]. The PlatformIO IDE has a built-in library that provides access to many simple I/O routines.

4. Conclusion

The digitalization of the transport sector is a global trend that creates new conditions for the functioning of human society. IoT technologies are not only the main feature of a smart city, but are also aimed at improving the quality of life of the population, increasing the efficiency and availability of city services, increasing the level of safety and environmental protection, and developing the socio-economic system of the city. The developed scientific and methodological approaches to assessing coordinates and recognizing objects of the transport infrastructure of a smart city allow ensuring the reliability and safety of urban systems and the efficiency of resource use.

At the same time, the transition to the smart city model is limited by the lack of a technical base for creating IoT information technology platforms. A roadmap for the digital transformation of the national economy has not been developed. Therefore, the main obstacles to the digital transformation of cities are the underdevelopment of technological solutions in the field of standardization of new technologies and work with big data. Modeling the functioning of the transport infrastructure of smart cities, in particular the collection and use of big data for this purpose, is of great interest for further scientific research.

Acknowledgments

The article is prepared with the financial support of the Russian Science Foundation, project № 19-78-10035.

References

[1] Amico G, Szopik K and Ioppolo G 2021 Sustainable Cities and Society 69 102801
[2] Zhao P, Lu C and Markham A 2021 Ad Hoc Networks 116 102475
[3] Hoang L, Kim M and Kong S 2019 IEEE Transactions on Signal Processing 67 3516-30
[4] Ma B, Zhu W and Huang Q 2021 Journal of Applied Geophysics 190 104342
[5] Tong Z, Gao J and Yuan D 2020 Construction and Building Materials 258 120371
[6] Sagnard F, Norgeot C and Lebental B 2016 Measurement 88 318-30
[7] Deng T, Zhang K and Shen Z 2021 Journal of Management Science and Engineering 6 125-34
[8] Lai W, Derobert X and Annan P 2017 NDT & E International 96 58-78
[9] Mohamed N, Jaroodi J and Mohammed F 2018 Technological Forecasting and Social Change 153 119293
[10] Qadir Z, Ullah F and Turjman F 2021 Computer Communications 168 114-35
[11] Khan N, Jhanjhi N and Nayyar A 2020 Computer Communications 157 434-43
[12] Outay F, Mengash H and Adnan M 2020 Transportation Research Part A: Policy and Practice 141 116-29
[13] Alsamhi S, Afghah F and Guizani M 2021 Ad Hoc Networks 117 102505
[14] Ge C, Ma G and Liu Z 2020 Journal of Systems Architecture 107 101728
[15] Ullah Z, Turjman F and Gagliardi R 2020 Computer Networks 182 107478
[16] Kumari A, Gupta R and Tanwar S 2021 Computer Communications 172 102-18
[17] Alsamhi S, Afghah F and Guizani M 2021 Ad Hoc Networks 117 102505
[18] Camprodon G, Gonzalez O and Bizzotto A 2019 HardwareX 6 100070