Modeling of Healthcare Monitoring System of Smart Cities

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***Abstract*- With the rapid development of information and communication technologies, the concept of a smart city has become a reality, and these smart cities are constantly increasing in most countries of the world because of the desire of governments to enhance the lives of their citizens and increase both efficiency and sustainability. The main idea of the concept of smart cities is to integrate the system of services in the cities such as health, energy, education, transportation, and public services, and provide them to citizens everywhere. As health monitoring is one of the most important applications of a smart city, this paper presents the issues of modeling a system for monitoring the health of various population groups of a smart city. The relevance of such systems is caused by the emergence of fundamentally new types of cities, an increase in the number and average life expectancy of the population, and the emergence of new diseases caused by climate change. The peculiarity of the system lies in its complex nature, i.e., it solves the problem of assessing the status of people requiring medical care, calling medical personnel, and monitoring the effectiveness of clinics by the government.**

***Keywords* - medical informatics, healthcare, smart city, modeling, monitoring system.**

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1. Introduction

As a result of fundamental technological, economic, political and social changes in the XXI century, new types of organizational and technical systems (OTS) have appeared and are rapidly developing. They differ from traditional OTS in the deep integration of information technologies in all areas of the population’s life, including: production, transport, energy supply, healthcare, management, education, leisure, etc. [1], [2]. The most important group of new OTS are the so-called smart cities (Smart Cities) [2], [3]. Building a smart city is a complex, multifaceted and large-scale problem that is being solved by the leading countries of the world [4]. The most important advantage of a smart city is the control of the most important components of the life cycle of the city with the help of computer technology and the adoption of effective operational decisions in the event of an emergency. One of the primary tasks in building a smart city is to digitally transform healthcare, i.e., the construction of computerized clinics, communications, and intelligent systems for monitoring health and improving the quality of life of various population groups [2], [5]. The relevance of this task is caused by a number of objective factors:

1) A rapid increase in the urban population due to the outflow of people from rural areas,
2) An increase in the average life expectancy of a person,
3) A shortage of qualified medical personnel and the high cost of medical supervision and treatment.

The most difficult situation is for people with disabilities, veterans, pensioners, and the elderly, the number of which, according to the World Health Organization [5], [6], have reached one billion and are constantly increasing.

The task of providing timely assistance to these population groups in most countries is being solved extremely slowly, because traditional methods of medical care in many ways do not correspond to the scale or complexity of new health problems. In addition, the city administration must promptly evaluate the effectiveness of the clinics and constantly provide them with assistance to improve the health of the population. Thus, three tasks are relevant:

- An autonomous assessment of the patient's condition, making an appropriate decision and sending an appropriate message to the clinic.
- Confirmation and implementation of the decision in the clinic (selection and dispatch of medical personnel), accumulation of statistics.
- Analysis of statistics on the activities of clinics by the city administration and assisting them if necessary (for example, during epidemics).

The most difficult situation is for people with disabilities, veterans, pensioners, and the elderly, the number of which, according to the World Health Organization [3], [7], [8], have reached one billion and are constantly increasing. The task of providing timely assistance to these population groups in most countries is being solved extremely slowly because traditional methods of medical care in many ways do not correspond to the scale or complexity of new health problems. In addition, the city administration must promptly evaluate the effectiveness of the clinics and constantly provide them with assistance to improve the health of the population. Thus, three tasks are relevant:

An autonomous assessment of the patient's condition, making an appropriate decision, and sending an appropriate message to the clinic. Confirmation and implementation of the decision in the clinic (selection and dispatch of medical personnel), accumulation of statistics. Analysis of statistics on the activities of clinics by the city administration and assisting them if necessary (for example, during epidemics). A comprehensive solution to these problems will ensure the synchronization of relations between patients, medical personnel of clinics, and city administration [9]. One of the most effective solutions is to develop specialized intelligent systems that fix the patient's problem situations, evaluate them, call the appropriate medical personnel, conduct a daily analysis of the clinics and evaluate their performance by the administrative authorities.

In this paper, we consider the option of constructing a health monitoring system for individual population groups, the peculiarity of which is that it can be deployed on top of existing clinical systems on the basis of the HLA (High-Level Architecture) principle [9], [10], and does not require a change in the principles of their work. Understanding the terms, we form a conceptual framework that reflects the realities of the post-industrial world and is unambiguously understood by customers, designers, and programmers [11], [12], [13]. *A smart city* - is a hierarchical large-scale heterogeneous OTS, the life cycle of which is provided by information *The actor of a smart city* - is a person, organization, intellectual program, technical device, process, and other entities integrated into the infrastructure of a smart city. Initially, actors are believed to have sensors and can exchange information over the Internet. This definition reflects the realities of the information society. Within the framework of monitoring tasks, actors should be classified into three groups depending on the level of development of intelligence: ni-people with natural intelligence; ai - artificial intelligence systems; noi – technical devices, objects and processes equipped with sensors, but without decision-making systems.

2. Research Background

A sensor - is a technical device that fixes certain parameters of an actor, performs their initial processing and sends the result to other actors. Fixing the value of the parameters, and a controller that performs their initial processing and sending to a specific address.

Administration (center) - an actor of the upper level of the hierarchy, managing the life cycle of a smart city.

Artificial Intelligence (AI) - is a specialized self-learning program (ai) that solves intellectual problems faster and better than a person. Clinic is a medical institution providing remote monitoring and medical services for various population groups.

The patient- is an actor of the observed group of the population (disabled person, veteran, pensioner), who is under remote medical supervision.

A population group monitoring system - is a system for monitoring and synthesizing control decisions for people requiring prompt medical care based on wearable or implanted sensors.

Based on a set of definitions, we formulate the statement of the problem.

3. Formulation of the Problem

Let there be a smart city, managed by the administration (C) with the help of an intelligent decision support system (aiC). The population of the city consists of various groups of actors. One of them is people (P) who need constant medical supervision. Actors P have sensors (dt) that fix their diagnostic parameters (X) and intelligent controllers (aiP) that determine the condition (V) of the patient and form the control solution (U), which is transmitted through the channels to a specialized medical organization - clinic [14], [15]. Clinics (K) have qualified personnel (staff), an AI system (aiK), a knowledge base containing the medical history of actors P, and access to other useful information, including patient cards in the international FHIR format (Fast Healthcare Interoperability Resources). It is required to develop a monitoring system for actors P, K, and C providing: fixing the patient's parameters, determining his condition, calling the appropriate medical personnel, and monitoring the work of the clinic by the administration of the smart city. The solution to this problem meets a number of difficulties. First of all, this is a gigantic number of P actors, the heterogeneous nature [16], [17], [18], of the X parameters (string, integer, real, Boolean, char), a large amount of information flow from P to K, the complexity of accounting for the implementation of decisions in each individual clinic and the evaluation of the activities of all clinics by the city administration.

4. Models and Algorithms

Models at the initial stage of modeling large-scale OTS [19]. This includes a smart city, it is advisable to apply an ontological approach which consists of the construction of conceptual models and their sequential refinement up to the program code [20], [21].

The ontology of a smart city in the framework of the set can be represented as:

$$mSC = (C, aiC, K, aiK, P, aiP, com) \quad (1)$$

where: C - city administration; aiC - AI administration; K - clinics; aiK - AI clinics; P - patients; aiP - patient AI; com - communications for data exchange between aiC, aiK, aiP.

4.1. AI ontology for city Administration:

$$aiC = (idC, adrC, rC, listK, adrK, WPM, com) \quad (2)$$

where: idC - identifier; adrC - address; rC - administration resources; listK - list of clinics; adrK -clinic address; WPM - workload per medic (doctors and nurses).

4.2. Clinical AI ontology

$$aiK = (idK, adrC, adrK, listidP, adrP, FHIR, rK, com) \quad (3)$$

where: idK - clinic identifier; adrC - address of the city administration; adrK - clinic address; listidP - list of patient identifiers; adrP - patient addresses; FHIR - database of uniform electronic cards according to the FHIR standard; rK - clinic resources.

4.3. Ontology of AI for the patient

$$aiP = (idP, FIO, adrP, adrK, dt, X, V, U, com) \quad (4)$$

where: idP - patient ID; FIO - name of the patient; adrP - patient address; adrK - clinic address; dt - sensors; X - parameter values; V is the state; U is the control solution.

5. Input Normalization

The input data <X> received from the sensors can be of a type that complicates mathematical processing, for example, string or char. To eliminate this drawback, one can use the membership functions of the theory of fuzzy sets [8], [18], [22], representing values of any type on the interval [0.00-1.00]. For example, f → <X1> X€ [0.00 -1.00]. By dividing the range [0.00-1.00] into sub bands with the help of an expert, we can obtain a structure convenient for a qualitative assessment of the state V and the synthesis of the corresponding solution U. For example:

If X in [0.00-0.25] then V = "good "and U = "keep watching"

If X in [0.26-0.50] then V = "medium "and U = "call nurse"

If X in [0.51-0.75] then V = "tolerably "and U = "call doctor"

If X in [0.76-1.00] then V = "bad "and U = "call an ambulance"

Based on models and normalized data, we construct a monitoring algorithm.

5.1. Algorithms

Before implementing the algorithm, it is assumed that the system is deployed, all patients have smart sensors and universal FHIR cards in the clinic database.

5.2. Patient-level

Step 01. Fixing by dt sensors the values of the patient's parameters <X>.
Step 02. The mapping <X> →X€ [0.00-1.00].
Step 03. Analysis X.
Step 04. Determination of the state V and synthesis of the control solution U;
Step 05. Sending the message < idP, V, U > to the clinic.

5.3. Clinic Level

Step 06. Receiving the message <idP, V, U> from idP;
Step 07. Forming a data package for idP corresponding to U;
Step 08. Formation of a group of medical staff and visit to the patient adP;
Step 09. Assisting, using the resources of the clinic and the city;
Step 10. Reflection of the results of the visit to the database.

5.4. City Administration Level

Step 11. Activation of aiC;
Step 12. Analysis of the database of clinics, summarizing data on calls and personnel involved for each district of the city;
Step 13. Assessment of the quality of clinics in each district;
Step 14. Assist the clinics if necessary at the expense of the city resources. Based on models and algorithms, a set of monitoring programs has been developed, which is discussed below.

6. Architecture of Monitoring System

The main problem with building architectures for monitoring systems is the diversity of their composition and structure. As a result, each system is an expensive original product that is difficult to master and upgrade software code. To reduce the cost of development, a unified version of the architecture is proposed that is invariant to the features of the city. The architecture includes modules integrated with sensors, iP, aiK, aiC, a database of clinics connected by communications Figure 1.

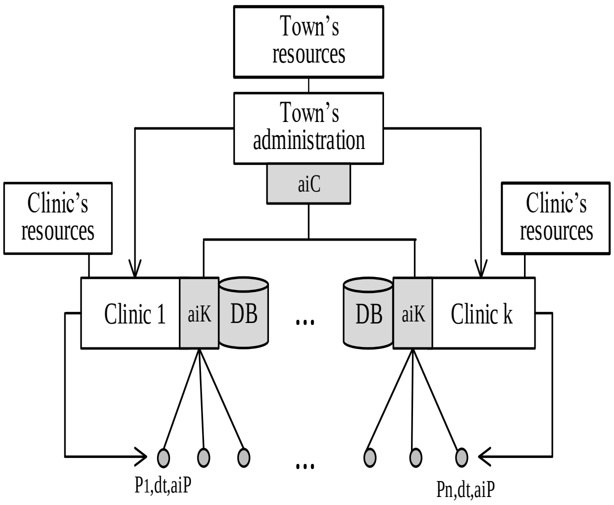

Figure 1. The architecture of a public health monitoring system

This architecture option has the properties of universality, scalability and is focused on the exclusion of man (niC, niK) from decision-making processes as AI improves which will accelerate the response to dangerous situations, improve the quality of medical care and give significant cost savings. A feature of architecture is the ability to evaluate the performance of clinics by the city administration on the basis of “hot” information, which allows you to quickly maneuver resources in the event of epidemics or natural disasters.

This architecture option is tough, but allows the flexible use of AI at each level by expanding the range of tasks they solve. For example, the monitoring task can be expanded by the tasks of analyzing the quality of clinics by city districts.

7. Healthcare Monitoring System

The development and implementation of monitoring systems for the components of a smart city is notable for its complexity and high cost. To reduce the cost at the first stage, simulation is used, during which the detected errors are determined and eliminated [22]. This article presents a variant developed experimentally in JavaScript, HTML5, and CSS3. The system consists of a city site, clinic sites, and intelligent patient data sources [23]. On the city's website, the main menu provides the administration with password access to data on the vital components of the city, including energy, transport, healthcare, education, etc. Figure 2.

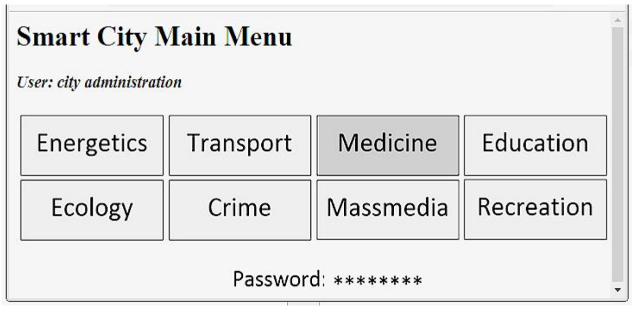

Figure 2. The main menu of the city administration

Smart sensors record the values of patient parameters; aiP synthesizes the control solution, displays it on the screen and sends it to the clinic. For example, the patient idP measures the parameters: X1 - pulse; X2 - blood sugar level; X3 - arrhythmia; X4 - blood pressure; X5 - body temperature. The obtained values are normalized, i.e., are displayed on the scale [0.00-1.00]. Depending on the worst value, a control decision is formed. For example, Figure 3., shows a situation where X4 = 0.76→V = “bad“→U = “call an ambulance“, i.e., the patient's blood pressure has risen to a dangerous level, therefore it is necessary to call an ambulance. Having received the call, the clinic AI using the idP identifier that forms a package of all available information about the patient and staff (staff: nurse, doctor, ambulance, etc.) necessary to provide assistance. All operations are recorded by aiK and visualized in Figure 4.

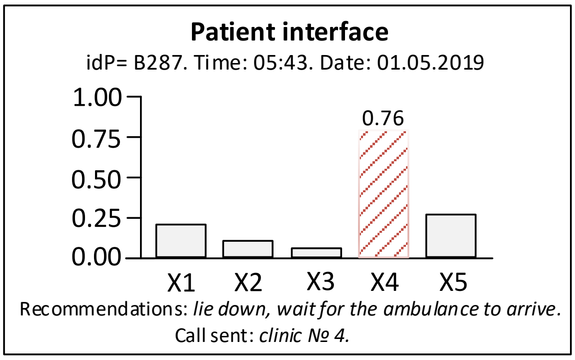

Figure 3. Patient interface

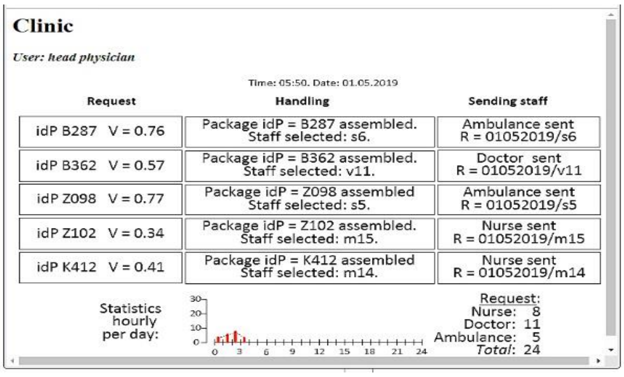

Figure 4. Clinic interface

The city administration has access to data on the work of clinics through the main menu Figure 2., after activating the "Medicine" mode. The screen displays statistics for all clinics. For example, Figure 5. shows the statistics of five clinics. Obviously, the doctors of Clinic No. 2 are loaded more than others (14.46 patients per 1 doctor) and they need help.

Thus, the system as a whole is complex [6], [24], because it solves the problems of assessing the condition of patients, calling the appropriate medical professional, and evaluating the activities of each individual clinic and all clinics in the city.

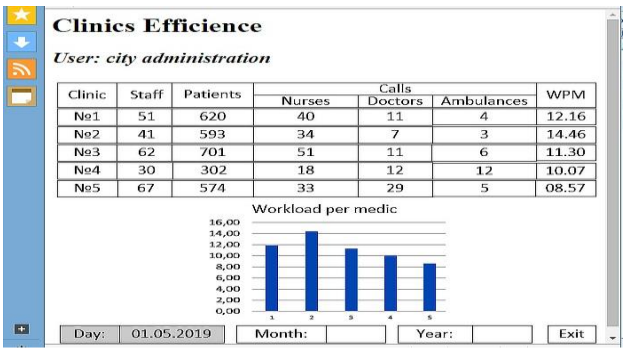

Figure 5. Interface for the city administration

8. Conclusion

This paper presents the proposed version of the architecture of the health monitoring system for various population groups of a smart city. Unlike other methods, as AI improves, our research is initially focused on reducing the role of humans in decision-making. Additionally, the developed system allows making quick decisions to strengthen the resources of clinics in critical situations, for example, when epidemics occur. The current study highlights the normalization of input data at the sensor level which allows for creating and using the same mathematical apparatus for processing heterogeneous data types including string data types. As a result of standardization, it became possible to build mini-sensors with minimal memory and maximum solution synthesis speed.
Finally, this research's main concern is to ensure timely delivery of health care to those in need and reduce the waiting period to induce health services by the government.

References

[1]. Herzberg, C. (2017). *Smart cities, digital nations: Building smart cities in emerging countries and beyond*. Cameron+ Company.

[2]. Brown, G. D., Patrick, T. B., & Pasupathy, K. S. (2012). *Health informatics: a systems perspective*. Chicago, IL: Health Administration Press.

[3]. Hersh, W. R., & Hoyt, R. E. (2018). *Health Informatics: Practical Guide Seventh Edition*. 7th ed. Information Education.

[4]. Al-Oqaily, A. T., & Shakah, G. (2018, July). Solving non-linear optimization problems using parallel genetic algorithm. In *2018 8th International Conference on Computer Science and Information Technology (CSIT)* (pp. 103-106). IEEE. https://doi.org/10.1109/CSIT.2018.8486176

[5]. Braunstein, M. L. (2018). *Health Informatics on FHIR: How HL7's New API is Transforming Healthcare*. Springer International Publishing.

[6]. Celino, I., & Kotoulas, S. (2013). Smart cities [guest editors' introduction]. *IEEE Internet Computing*, *17*(6), 8-11. https://doi.org/10.1109/MIC.2013.117

[7]. Gelogo, Y. E., Hwang, H. J., & Kim, H. K. (2015). Internet of things (IoT) framework for u-healthcare system. *International Journal of Smart Home*, *9*(11), 323-330. http://doi.org/10.14257/ijsh.2015.9.11.31

[8]. Zadeh, L. A., Klir, G. J., & Yuan, B. (1996). *Fuzzy sets, fuzzy logic, and fuzzy systems: selected papers* (Vol. 6). World Scientific.

[9]. Sánchez, L., Elicegui, I., Cuesta, J., Muñoz, L., & Lanza, J. (2013). Integration of utilities infrastructures in a future internet enabled smart city framework. *Sensors*, *13*(11), 14438-14465. https://doi.org/10.3390/s131114438

[10]. Bawany, N. Z., & Shamsi, J. A. (2015). Smart city architecture: Vision and challenges. *International Journal of Advanced Computer Science and Applications*, *6*(11). https://doi.org/10.14569/IJACSA.2015.061132

[11]. Adegboyega, O., Curry, E., & Janowski, T. (2014). Next generation smart city initiatives - Harnessing Findings and lessons from a study of ten smart city programs. *In 2014 Twenty Second European Conference on Information Systems. (ECIS)*, 1-14.

[12]. Serrano, W. (2018). Digital systems in smart city and infrastructure: Digital as a service. *Smart cities*, *1*(1), 134-154. https://doi.org/10.3390/smartcities1010008

[13]. Boussadi, A., & Zapletal, E. (2017). A fast healthcare interoperability resources (FHIR) layer implemented over i2b2. *BMC medical informatics and decision making*, *17*(1), 1-12.

[14]. Meijer, A., & Bolívar, M. P. R. (2016). Governing the smart city: a review of the literature on smart urban governance. *international review of administrative sciences*, *82*(2), 392-408. https://doi.org/10.1177%2F0020852314564308

[15]. Heaton, J., & Parlikad, A. K. (2019). A conceptual framework for the alignment of infrastructure assets to citizen requirements within a Smart Cities framework. *Cities*, *90*, 32-41. https://doi.org/10.1016/j.cities.2019.01.041

[16]. Yang, B. (2019). Developing a mobile mapping system for 3D GIS and smart city planning. *Sustainability*, *11*(13), 3713. http://dx.doi.org/10.3390/su11133713

[17]. Komninos, N., Bratsas, C., Kakderi, C., & Tsarchopoulos, P. (2016). Smart city ontologies: Improving the effectiveness of smart city applications. *Journal of Smart Cities (Transferred)*, *1*(1). http://doi.org/10.18063/JSC.2015.01.001

[18]. Espinoza-Arias, P., Poveda-Villalón, M., García-Castro, R., & Corcho, O. (2018). Ontological representation of smart city data: From devices to cities. *Applied Sciences*, *9*(1), 32. https://doi.org/10.3390/app9010032

[19]. Rijgersberg, H., Van Assem, M., & Top, J. (2013). Ontology of units of measure and related concepts. *Semantic Web*, *4*(1), 3-13. http://doi.org/10.3233/SW-2012-0069

[20]. Kang, M., Park, E., Cho, B. H., & Lee, K. S. (2018). Recent patient health monitoring platforms incorporating internet of things-enabled smart devices. *International neurourology journal*, *22*(Suppl 2), S76. https://doi.org/10.5213/inj.1836144.072

[21]. Yang, J. J., Li, J., Mulder, J., Wang, Y., Chen, S., Wu, H., ... & Pan, H. (2015). Emerging information technologies for enhanced healthcare. *Computers in industry*, *69*, 3-11. http://doi.org/10.1016/j.compind.2015.01.012

[22]. Minoi, J. L., & Yeo, A. W. (2014, December). Remote health monitoring system in a rural population: Challenges and opportunities. In *2014 IEEE Conference on Biomedical Engineering and Sciences (IECBES)* (pp. 895-900). IEEE. https://doi.org/10.1109/IECBES.2014.7047641

[23]. Islam, M. S., Hasan, M. M., Wang, X., Germack, H. D., & Noor-E-Alam, M. (2018, May). A systematic review on healthcare analytics: application and theoretical perspective of data mining. In *Healthcare* (Vol. 6, No. 2, p. 54). MDPI. https://doi.org/10.3390/healthcare6020054

[24]. Kamel, P. I., & Nagy, P. G. (2018). Patient-centered radiology with FHIR: an introduction to the use of FHIR to offer radiology a clinically integrated platform. *Journal of Digital Imaging*, *31*(3), 327-333. https://doi.org/10.1007/s10278-018-0087-6