www.jpis.az

15 (2)
2024

Application of cyber-physical geosystems in Healthcare 4.0 environment: challenges, opportunities and perspectives

Anar Samidov

Institute of Information Technology, B.Vahabzadeh str., 9A, AZ1141, Baku, Azerbaijan

anarsamidov@gmail.com

orcid.org/0000-0001-7173-7745

ARTICLE INFO

http://doi.org/10.25045/jpis.v15.i2.10

Article history:

Received 12 January 2024
Received in revised form
15 March 2024
Accepted 24 May 2024

Keywords:

Cyber-physical systems,
Geosystems
Emergency medical care
Route optimization
Telemedicine
Geographic information systems

ABSTRACT

In modern times, the use of information technologies in the automation of emergency medical care processes is of great importance. This study offers the application of cyber-physical geosystems to optimize and improve emergency medical care processes using geospatial information. Moreover, it presents the methodology of creating cyber-physical geosystems including the collection, analysis, monitoring and integration of geospatial data into medical information systems and the application of telemedicine. The main goal of cyber-physical geosystems is to increase the efficiency of patient care in emergency situations. Real-time monitoring of the patient in the ambulance by a doctor-expert is very important during the transportation of the patient from the scene of the incident or from the medical institution to the hospital equipped with modern equipment. Consequently, medical experts can give emergency doctors important instructions about the patient in time. This results in a reduction in response time in emergency situations and an improvement in the quality of medical care. This article discusses the importance, limitations, and advantages of using the technologies of cyber-physical geosystems in the context of modern emergency medical care. Correspondingly, it analyzes the advantages and limitations of the system, its expansion and improvement methods. The results of this study highlight the successful implementation of cyber-physical geosystems (CPGS) in different regions. In this regard, it recommends the necessity of joint cooperation with the state and medical institutions.

1. Introduction

The emergency medical service is an important element of the health care system and plays a key role in saving people's lives and ensuring the health of the population. However, providing effective emergency medical care in today's large cities and dynamically changing environment faces a number of challenges. These challenges include accurately defining the patient's location, optimizing emergency routes, and ensuring fast and quality communication between medical professionals and patients (Smith et al., 2020). In emergency situations, the operation process requires more responsibility to save the lives of patients. Well-integrated emergency medical services can play an important role in reducing life risk (B.Farmer, 2016).

Communication between emergency department and hospital service systems is essential during emergency medical services. Both systems should be integrated to facilitate data sharing. However, in the current situation, the medical center can get the detailed information about the patient's condition only after the patient is brought to the center, which leads to further

worsening of the patient's condition. Cyber-physical systems (CPS) in Healthcare 4.0 the application of the Internet of Things (IoT) can facilitate the processing of various data collected anywhere by hospitals (Rasim Alguliyev et al., 2011). The introduction of CPSs and IoT into the emergency care system can help integrate operational processes, so that emergency physicians can treat patients faster and more accurately (E. Park et al., 2018).

Cyber-physical systems. Cyber-physical systems (CPS) are integrated systems consisting of various natural objects, artificial subsystems and management controllers. CPSs provide close connection and coordination between computing and physical resources (Frazzona et al., 2013).

CPSs help make more accurate and timely decisions based on real events rather than human imagination. End-to-end digitization of technological processes will not exclude people from the decision-making process. This will only help to increase efficiency by simplifying the process (Irada Alakbarova, 2020).

The successful operation of the modern health care system is not only the implementation of therapeutic and preventive measures, but also the wide use of information technologies. An important component of informatization of the medical industry is the creation and implementation of cyber-physical geoinformation systems (CPGS) (Brown et al., 2019).

CPGS is an innovative approach that combines information technology, geospatial data and medical care to improve emergency care. These systems enable the efficient collection, analysis, and transmission of information about patient locations, medical resources, and traffic conditions, which in turn facilitates rapid and accurate response to medical situations (Gunes et al., 2000).

This study reviews the technologies and methods used to create CPGS in emergency medicine and explores their effectiveness in real-time conditions. The paper also analyses examples of successful CPGS applications and discusses their potential impact on the emergency care system in Healthcare 4.0.

2. Related work

A lot of work has been done to solve the issue of the placement and planning of emergency medical vehicles and medical facilities. (G. Erdoan et al., 2010). highlights the problem of allocating ambulances to stations distributed over a geographical area in order to maximize the expected coverage of an ambulance. The essence of the proposed method is to assign teams to shifts based on the maximum number of work hours that can be managed.

(A. Ingolfsson et al., 2008). describes an ambulance location optimization model that minimizes the number of ambulances needed to provide a given level of service. The model measures service level as the fraction of calls received within a given standard time and assumes that the response time consists of a random delay (before the incident occurs) and a random time on the road.

(J. Aubin, 1992). defines the problem of predicting emergency calls and allocating their working hours. It proposes a systematic optimization approach for emergency service scheduling and discusses how their method can save time and improve technicians' schedules.

(P. Sorensen et al., 2010), (Ayfer Başar et al., 2011), (S. Chanta et al., 2011), (V. Schmid et al., 2010) and (P. Yin et al., 2012) define the scope of facilities for emergency situations and discuss how it relates to the service life of requests, spatial coordinates and trajectories of movement.

(Mohammad et al., 2016). offers a route planning approach based on a new physiology (by opening the mechanism of execution of the activities of a living organism, studying the relationship between them, evolution and individual development processes) for emergency transportation of patients with high-risk group diseases who need continuous remote monitoring. The problem is mathematically modeled using fuzzy set theory, and a solution based on the trade-off between communication coverage and shortest path is provided. In a large rural hospital, a communication profile is created for two main routes, and how the concept works is observed. In addition, scalability is compared. The planning method is claimed to greatly support the telemetry monitoring system in preventing patient complications and mortality through early diagnosis and effective treatment.

(Anar Samidov et al., 2019). explores the possibilities, perspectives and application of 3D technology in medicine in details. Systems using 3D technologies and their role in all fields of medicine are analyzed. As a result of three-dimensional modeling, the general medical information obtained about the real condition of patients is recorded in the database of the system. The current system generates anatomically three-

dimensional images of organs that are difficult to examine, unlike traditional methods. Such three-dimensional images are used in diagnostics during surgical intervention.

In (Irada Alakbarova, 2023). the author explores the role of cyber-physical systems in the formation of a smart home environment based on human habits. The author proposes a new model based on the obtained data, putting security issues in the forefront of the smart home concept.

(Yadigar Imamverdiyev et al., 2021). discusses the current situation, essence, development prospects and security issues of GIS. The main direction of the research consists of modeling, formation of the national spatial database, further improvement of research in this field.

3. Current status of emergency medical care

The functioning of emergency medical services in different countries may face different shortcomings and vary depending on the region and the healthcare system (Anderson et al., 2018). Some of the common drawbacks that emergency medical services may face are as follows:

One of the main disadvantages is the delay of the ambulance brigade to the place of call. This can be due to the lack of ambulance crews, traffic jam, as well as weather conditions.

Difficulties in traveling to remote areas: In remote and rural areas, it can be difficult to ensure that emergency response teams arrive quickly and efficiently due to long distances.

Lack of resources: Unprofessional teams, as well as lack of medical equipment and supplies, can lead to limitations in the provision of medical care.

Poor coordination: Errors in dispatching calls can result in crews being sent to the most important prioritized problems or on non-optimal routes.

Inefficient information systems: Inadequately developed information systems and electronic health records make patient information unavailable to hospitals and other healthcare providers.

Overcoming these shortcomings requires improvement of coordination, financing, technical equipment and personnel training. The application of modern technologies such as cyber-physical geosystems can help improve the efficiency and accessibility of emergency medical services.

Fig. 1 shows the current state of the emergency medical service.

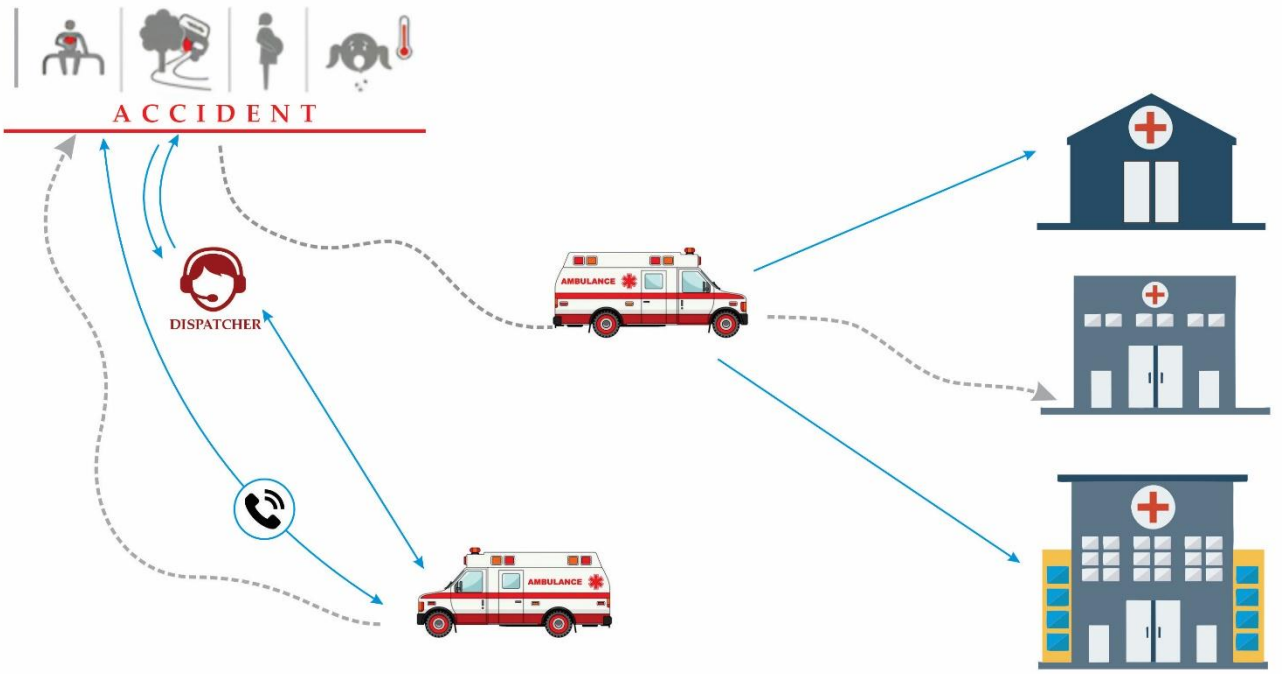

Fig. 1. Current status of emergency medical care.

4. Methodology of creation of CPGS in Healthcare 4.0.

1. Geospatial data collection and analysis. The first priority for creating a cyber-physical geosystem in emergency medical care is the collection and analysis of geospatial data (Johnson et al., 2016). For this, GPS and mobile devices, modern geographic information systems (GIS) and data collection technologies are used. The data

includes information about the location of patients, call points, emergency routes, as well as geographic features of the region (Lerner et al., 1999).

2. Integration with medical information systems. For effective organization and provision of emergency medical care, it is necessary to integrate CPGS with medical information systems (Parisasadat et al., 2024). This includes data synchronization with electronic medical records, patient management systems and healthcare facility databases. In this regard, data transfer standards and protocols are used, ensuring the security and privacy of medical data.

3. Route optimization and dispatching. CPGS also includes the optimization of ambulance delivery routes (Sarandis Mitropoulos et al., 2021). Here, optimization algorithms are developed based on information about road conditions, traffic jam, call types and available resources (Brotcorne et al., 2003). CPGS also includes dispatching functions that allow operational staff to effectively control and guide emergency response teams.

4. Application of telemedicine. One of the important aspects of CPGS is the ability to implement telemedicine solutions. It includes the integration of their video communication and real-time medical data transmission system for remote consultation of patients and remote monitoring of patients' condition by medical personnel (Garcia et al., 2017). Telemedicine consultations are available at the first stage of aid, significantly improving emergency response.

5. Personnel training and system testing. To ensure the successful implementation of CPGS, medical servants and dispatchers must be trained on the use of the system. The system should be tested in real-time conditions and the results analyzed to identify possible improvements in efficiency.

5. Advantages of cyber-physical geosystems in emergency medical care

As a result of the study, a number of significant advantages of using CPGSs in the emergency medical care system are identified:

- *CPGS significantly reduces the time required to accurately define the patient's location and provide medical care.* This allows for a faster response to emergency situations, which is important in lethal situations.
- *Improved coordination*: Integrating CPGS with health information systems improves coordination and information sharing between dispatchers, ambulance crews and medical facilities. This helps the emergency system to work efficiently.
- *Route optimization*: Using route optimization based on real-time information about road conditions allows reducing the time needed to provide medical care and making more efficient use of resources.
- *Implementation of telemedicine*: The integration of telemedicine into CPGS allows remote consultation and monitoring of patients, which improves the quality of medical care, especially in remote areas. Fig. 2 shows the proposed model of emergency medical care.

In the model of the emergency medical service proposed in Fig.2, CPGS is used very widely. Thus, from the first call to the dispatcher to the delivery of the patient to the medical center, the most modern communication technologies are used throughout the entire route. In addition, all types of situations are taken into account in the proposed model. In general, the whole process can be interpreted as follows:

- dispatcher is called first when the incident occurs;
- dispatcher analyzes the accident and guides the appropriate service to the address;
- before the fully equipped vehicle goes to the place, the route it will take, the landscape of the area (mountainous terrain, etc.), is already determined;
- in addition to initial information about the patient, all information about the patient is obtained by referring to the personal database;
- online connection is provided with a special vehicle along the way;
- if necessary, online consultation is provided;
- specially equipped drones are directed to the area if it is not possible to approach the scene;
- if there is a need to deliver the patient to the medical center, a vehicle equipped with special equipment is used.
- medical staff chooses the medical center to which the patient will be taken and the shortest route.
- preliminary information about the patient is transferred to the medical center.
- opportunity to conduct continuous mutual consultation with the medical center is provided.

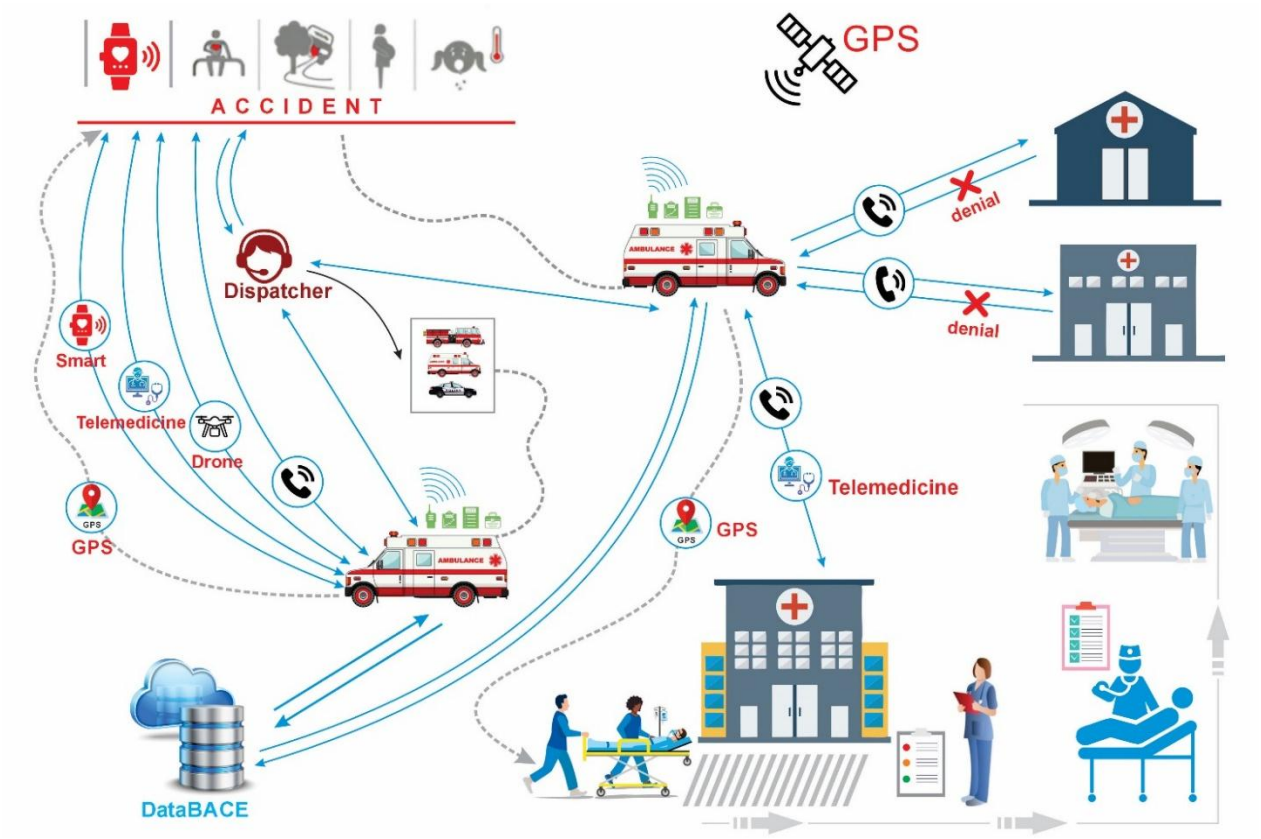

Fig. 2. Proposed model of emergency medical service (KFGS).

6. Discussions

Although there are many advantages when creating and using CPGS, there are some limitations and challenges to be aware of:

- *Data confidentiality*: The protection of medical and patient data is an important consideration during the development of CPGS. Strict security and privacy standards must be followed.
- *Technical challenges*: CPGS requires the integration of various technologies and systems, which in turn requires highly skilled professionals.
- *Funding*: The development and implementation of CPGS may require significant investment. Financial support from the state may be necessary for the successful implementation of the system.

The future development of cyber-physical geosystems in emergency medical care provides a number of perspectives:

- *CPGS can be applied to a wider area.* It may cooperate with other health facilities and emergency services.
- *Innovation*: The use of artificial intelligence and the development of new technologies, such as data analytics, can improve the functionality of the CPGS and help the system work more efficiently.
- *Global application*: CPGS has the potential to become a global standard for emergency medical care management in different countries and regions.

7. Conclusion

In conclusion, the results and discussion showed the creation of cyber-physical geosystems in emergency medicine to have the potential to fundamentally change the field in Healthcare 4.0. However, the implementation and development of CPGS requires significant efforts in the areas of data security, technical expertise and funding. Collaboration between health care providers, government agencies, and technology companies can contribute to the successful implementation and continued development of CPGS by providing faster and better access to emergency care.

Based on the research and analysis, the following main conclusions can be drawn:

1. CPGS is a powerful tool for optimizing and improving emergency medical systems. Their use significantly reduces reaction time, improves coordination and allows more efficient use of resources.

2. Integration of CPGS with health information systems and telemedicine technologies improves the accessibility of health information and improves the quality of medical care, especially in emergency situations.
3. However, establishing and implementing CPGS faces challenges such as data security and funding. These challenges require attention and solutions from healthcare professionals, government agencies and technology companies.
4. Prospects of CPGS: scalability, innovation, etc. can be applied to different fields.

To put it briefly, the creation of cyber-physical geosystems in emergency medical care is an important issue that can improve the accessibility and responsiveness of medical care, ultimately helping to save lives and improve public health. Successful implementation of this technology requires collaborative efforts and partnership between healthcare professionals, government agencies, and technology allies.

References

Ayfer Başar, Bülent Çatay, Tonguç Ünlüyurt (2011). "A taxonomy for emergency service station location problem," Optimization Letters, 6(6), 1147–1160, https://doi.org/10.1007/s11590-011-0376-1

A. Ingolfsson, S. Budge, and E. Erkut (2008). "Optimal ambulance location with random delays and travel times," Health Care Management Science, 11(3), 262–274,. http://dx.doi.org/10.1007/s10729-007-9048-1

Anar F. Samidov, Zulfiya R. Hanifayeva (2019). The state-of-the-art of 3d technologies and their development perspectives // Problems of Information Society, 10(1), 77–85, DOI: 10.25045/jpis.v10.i1.08

Anderson, M. P., & White, S. K. (2018). "Optimizing Ambulance Routing in Urban Areas: A Case Study of New York City". Journal of Emergency Medical Services, 40(2), 85-97.

B.M. Farmer (2016). "Patient Safety in the EmergencyDepartment," Emergency Medicine, 48(9), 397–404.

Brotcorne, L.; Laporte, G.; Semet, F. Ambulance location and relocation models. Eur. J. Oper. Res. 2003, 147, 451–463.

Brown, L. K., & Martinez, E. (2019). "The Role of Cyber-Physical Systems in Modern Emergency Medical Response." International Journal of Health Technology, 12(4), 521-536.

E. Park, J. H. Kim, H. S. Nam, and H. J. Chang (2018). "Requirement Analysis and Implementation of SmartEmergency Medical Services," IEEE Access, 6, 42022–42029, https://ieeexplore.ieee.org/document/8423628

Frazzona E.M., Hartmannb J., Makuschewitzb T., Scholz-Reiterc B. (2013). Towards Socio-CyberPhysical Systems in Production Networks / Proceedings of the Forty Sixth CIRP Conference on Manufacturing Systems, 49–54.

G. Erdoan, E. Erkut, A. Ingolfsson, and G. Laporte (2010). "Scheduling ambulance crews for maximum coverage," Journal of the Operational Research Society, 61, 543-550.

Garcia, R. A., & Patel, N. S. (2017). "Telemedicine in Prehospital Emergency Care: A Review of Current Technology and Research." Prehospital Emergency Care, 32(1), 112-125.

Gunes, A.E. and Kovel, J.P. (2000) Using GIS in Emergency Management Operations. Journal of Urban Planning and Development, 126, 136-149. http://www.sciencedirect.com/science/article/pii/S0143622811002360

Irada Y. Alakbarova (2020). The role of cyber-physical systems in Industry 4.0. Journal of Problems of Information Technology, 11(2), 91–101.

Irada Y. Alakbarova (2023). "Development of a model for the analysis of human behavior in a smart home environment" Problems of Information Society, 14(1), 75-84

J. Aubin (1992). "Scheduling ambulances," Interfaces, 22, (2), 1 –10.

Johnson, D. W., & Smith, P. R. (2016). "Geospatial Information Systems in Emergency Medicine: Applications and Challenges." Emergency Medicine Journal, 28(6), 483-496.

Lerner, E.B., et al. (1999) Use of a Geographic Information System to Determine Appropriate Means of Trauma Patient Transport. Academic Emergency Medicine, 6, 1127-1133.

Mohammad Hosseini, Yu Jiang, Poliang Wu, Richard B. Berlin Jr., Shangping Renx, Lui Sha (2016). "A Pathophysiological Model-Driven Communication for Dynamic Distributed Medical Best Practice Guidance Systems" Journal of Medical Systems, 40 article number 227, DOI:10.1007/s10916-016-0583-5

P. Sorensen and R. Church (2010). "Integrating expected coverage and local reliability for emergency medical serviceslocation problems." Socio-Economic Planning Sciences, 44(1), 8–18. http://www.sciencedirect.com/science/article/pii/S0038012109000214

P. Yin and L. Mu (2012). "Modular capacitated maximal covering location problem for the optimal siting of emergency vehicles," Applied Geography, 34, 247 – 254

Parisasadat Shojaei, Elena Vlahu-Gjorgievska, Yang-Wai Chow, Security and Privacy of Technologies in Health Information Systems: A Systematic Literature Review, Computers 2024, 13(2), 41; https://doi.org/10.3390/computers13020041

Rasim M. Alguliyev, Rasim Sh. Mahmudov (2011). The Internet of Things: essence, potentials and problems // Problems of Information Society, 2(4), 29-40.

S. Chanta, M. E. Mayorga, and L. A. McLay (2011). "Improving emergency service in rural areas: a bi-objective covering location model for ems systems," Annals of Operations Research, 221(1), 133–159. http://dx.doi.org/10.1007/s10479-011-0972-6

Sarandis Mitropoulos, Christos Mitsis, Petros Valacheas and Christos Douligeris. "An online emergency medical management information system using mobile computing Sarandis Mitropoulos" Journal of Applied Computing and Informatics. ISSN: 2634-1964, DOI:10.1108/ACI-03-2021-0069

Smith, J. A., & Johnson, B. R. (2020). "Integration of Geospatial Data in Emergency Medical Services: A Review." Journal of Health Geography, 25(3), 345-362.

V. Schmid and K. F. Doerner (2010). "Ambulance location and relocation problems with time-dependent travel times," European Journal of Operational Research, 207(3), 1293–1303, http://www.sciencedirect.com/science/article/pii/S0377221710004728

Yadigar N. Imamverdiyev (2021). On topical scientific and theoretical problems of geographic information systems in the big data environment Journal of Problems of Information Society, 12(2), 38–51, DOI: 10.25045/jpis.v12.i2.03