The Information Technologies in the Control Mechanism of Medical Processes

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Abstract— **Nowadays healthcare is on the verge of significant changes. The problems caused by COVID-19 make healthcare reconsider the approaches used for communication between doctors and patients and control the quality of treatment in general.**

The purpose of the scientific work is to develop a design for a controlling mechanism of medical processes, which will allow planning and managing medical processes using information technologies. For greater control flexibility, it should be possible to flexibly change process configurations on purpose.

Keywords— healthcare, medical processes, information technologies, health systems, medicine

I. Introduction

In modern world, where technology is evolving very rapidly and is already an integral part of human life, most people lack the knowledge and practical experience to apply it correctly. As well as most systems have various technical and logical shortcomings, that is related to system complexity and can't provide desired quality. However technical side of the problem is not the major one, many sectors including medicine are not ideally designed in order to improve their performance using information technologies [1].

COVID-19 spread shown real preparedness of countries' medical departments for extraordinary situations and ability to work in standard mode for routine situations, providing options to avoid patient's physical attendance and giving opportunity to communicate doctor at a distance using information technologies. Modern healthcare systems allow to get blood samples right at patient's place, so patient have no need to leave it to get basic health examination that will reduce risk of infection in medicine facility and allows to take more patients during a day. However, when medical help and diagnostics can be provided remotely, security of all sensitive data must be considered in order to keep patient's personal information safe and keep processing large data flow within telemedicine system.

II. Telemedicine

Telemedicine system is a system that allows patients and medicine specialists to remotely interact with each other using telecommunications and information technology [2]. The main advantage of telemedicine system is that both the patient and the doctor remain safe and there is no risk of being infected by different viruses [3]. For sure, it might be uncomfortable for both sides to use new communication approach as it limits set of actions that could be done during standard examination procedure and not all patients have opportunity to use information technologies for many reasons. Despite the possible problems that come with telemedicine usage, everyone including patients and medical specialists will gain much more profit, especially those who have transportation problems for physical or economic reasons.

For faster and more effective implementation and integration of telemedicine into healthcare, it is necessary to stick to step-by-step strategies and follow basic rules [4]:

- Assessing the maturity of the medicine system, for telemedicine module integration, where both the health care information system and the readiness of the internal regulation to introduce new services are offered, as well as to identify the current shortcomings of workflows.
- Identify organizational requirements, document business needs and prioritize each need, as well as identify technology requirements that meet the organization's goals and needs.
- Optimize business and operational regimes by restoring and adapting existing workflows, including identifying services in the target area's healthcare provider to expand telemedicine functionality.
- Set priorities and establish own roadmap to be able to adapt independently and continuously to the innovations arising from the rapid telemedicine development.

Medical industry consists of various processes that are important for healthcare to fulfill all patient and medical staff needs. Using a unified cyber-physical information system, medical institutions would be provided with up-to-date information on new diseases, their treatment options, as well as analysis of existing patient information and forecasting patient's health state, which would allow to prevent in time problems that may become irreversible in the future. In order to use cyber-physical information system for medical needs, medical processes must be analyzed first. One of the clearest examples of such a process is the technological process of disease prevention, which consists of the following stages:

- Prevention phase - the purpose of the phase is to prevent deceases. This process is usually done by the patient himself, receiving all the necessary information from the doctor (allowed physical activity, proper diet and information about possible diseases and risks). Therefore, monitoring of patient state using

information system with monitoring device help can be used to track this stage. [5][6][7]

- Discovery stage - one of the most important stages, on which all subsequent stages depend. The sooner a disease is detected, the better, because it is possible to prevent serious consequences with deteriorating health. For health monitoring purposes, it is necessary to hand over analyses and / or use POCT devices to be able to see the health picture at a given time. However, the results of the devices and analyses. However, in order to make a diagnosis, it is necessary to know the patient's state of well-being, that can be received using consultation and data received from devices and analyses results. [5][8]
- Diagnosis stage – is stage when the diagnosis is made, as well as the stage of the disease is clarified. The results obtained at this stage affect the treatment phase, so it is very important to avoid errors during the diagnosis phase as it could lead to unpredictable results. According to statistics, the highest number of errors is at this stage, so it is necessary to adhere to the correct observance of technological processes. [9][10]
- Treatment stage - a process based on all the results obtained in previous stages. In order to receive a positive result at this stage, the doctor needs to participate as much as possible in the process, using medical devices if necessary.
- Surveillance stage - depends on the disease, as it is not always necessary to monitor patient after the end of the treatment stage. However, the process takes place only after the completion of the basic treatment process and is important to make sure that patient's health condition has not worsened.

III. Cyber-Physycal Systems in Medicine

A cyber-physical system is a concept of specialized computing systems consisting of a sensors, communication and control devices that interact with each other via Internet protocols. There are several benefits to using such a system, such as [11][12]:

- Improving communication between doctors and patients.
- Standardized work processes.
- Quick access to medical data and documents in an electronic environment.
- High level of quality.
- Process automation.

The efficient functioning of the medical system requires that cyber-physical systems in medicine perform the following tasks [13]:

- Decide which medical data storage format to use so data could be used as quickly and efficiently as possible.
- Determine what medical data is needed for storage, how and for what purposes it will be used.
- Identify medical workflows that can be automated or that can potentially become part of a medical information system.
- Provide standardized communication between devices.
- Develop medical decision support systems, applying data mining to medical data processing, which will help medical professionals and researchers to gain new knowledge about treatment options.

Like any other information system, cyber-physical system has its own integral components that are necessary for the proper functioning of the system: time, complexity, data validation and security.

- Time - is an integral part of the system, as it is necessary to provide real-time information and its synchronization. One of the known technologies for time synchronization can be used in cyber-physical systems: Ethernet time accuracy protocol IEEE 1588, time trigger busses, wireless time synchronization protocols. One of the most popular information indexing tools is considered to be a time stamp, which is usually also used in the data acquisition processes of cyber-physical systems. Another possible option that can be used is time triggers, but only in cases where the system is not involved in security measures [14].
- Complexity is a characteristic that shows the difficulty of solving a data processing problem and is usually expressed in terms of consumed resources for that problem solving. In terms of complexity of the system, one can distinguish parameters by which system's complexity can be determined - structure, dynamics, and organization. Structural complexity addresses issues that may arise within a system architecture. For example, a system may consist of several units, and the principles of interaction between these units may be difficult to understand. The level of dynamic complexity of a system depends on its functionality, so if it is difficult to predict the behaviour of the system, then such a system will be considered dynamically complex. Organizational complexity directly depends on the degree of differentiation between the various elements, which form a single system, which includes the structure of project development processes and also the organizational structure of the people who are working on the project [15][16].
- Data validation is an integral part of the development and integration of a cyber-physical system, which includes verification and validation processes. The following methods can be used for validation - modelling, testing, simulation. With the help of these methods it is possible to check whether the logic and behaviour of the cyber-physical system is correct and corresponds to the set goals and objectives. System testing is effective when it is divided into several subsystems and each of them is tested separately. The analysis of the results is performed only when each subsystem goes through the testing process, then testing can be started at the level of complexity [14][17].
- Security is the most important aspect of cyber-physical systems, which affects the reliability and

confidentiality of the data transmitted, as well as the availability of the system during continuous communications. Due to the large amount of data and real-time data exchange, it is necessary to develop control and security algorithms together with the integration platform. The security of cyber-physical systems is divided into four main categories: confidentiality, availability, integrity, and maintenance [12][18][19].

IV. Cyber-Physical System for the Control of Medical Processes

As was already mentioned, the main goal of the medical information system is to receive and process patient data as efficiently as possible, minimizing waiting time.

To develop medical cyber-physical information system requirements must be specified first.

TABLE I. Basic requirements for medical cyber-physical systems

Functional requirements	Non-functional requirements
User training environment	Fast response time
Patient user interface	Real-time operation
Medical staff user interface	Damage tolerance
Reading the patient's condition	Security
Remote consultation	Confidentiality
Information exchange using sensors	Flexibility
Big Data processing, data mining application	Support for medical device standards and regulations
	Integration support

As a base for cyber-physical system with medical process control mechanism should be used centralized cyber-physical system architecture as all of it components and layers fit to described requirements. Described architecture is divided into four main layers [20]:

- Physical layer – interacting with the patient by receiving information about the patient's condition from medical devices.
- Communication layer – is responsible for data transmitting between physical layer and intelligent service layer using IoT hub in cloud, API for communication and also communicator that transmits data from medical devices to centralized information system.
- Intelligent Service layer – is main centralized medical cyber-physical system layer as system core is based on it. It consists of multiple modules for various functionality implementation and provide all business logic processing for telemedicine and medical process control purposes.
- Data Analysis layer – provides resources for risk assessment and prognoses based on patient's health data and analysis results.

V. Use of the Cyber-Physical Information System for the Control of Medical Technological Processes

In medicine, the purpose of a cyber-physical information system is to improve the current state of patient's health. A unified control system with the possibility to give trained specialists the opportunity to define and describe new medical technological processes can provide flexible and semi-automatic control of medical processes, which will also allow assessing the professional activities of specialists and revealing shortcomings in treatment methodologies.

Developing a system based on the cyber-physical system architecture described in previous chapter, the process control functionality should be developed as a separate module that will allow medical institutions to decide whether such functionality is necessary for full operation of the institution or not, checking if it is useful to use resources for medical staff training.

A. Creating a medical process template

In medicine, there is an opportunity to solve the problem with a number of descriptive technological processes, so the doctor would be able to choose a more appropriate method based on the data received from the patient. Medical technological processes are sequential and form a process, which is also could be the part of another technological process. In the medical process template, it is necessary to create dynamic technological processes that could be adapted to a specific stage, changing the criteria, event behaviour, workflow stage order.

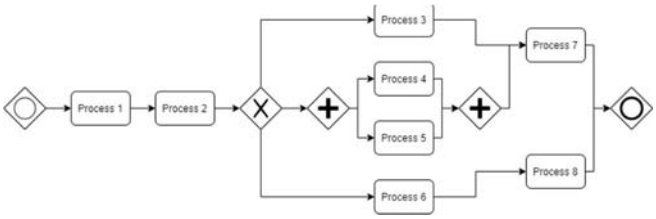

Fig. 1 Example of a process workflow template

During template creation multiple aspects must be kept in mind:

- Decomposition - by applying decomposition methods, it is possible to divide one process into several smaller processes, where each process will be responsible for a separate functionality. To provide efficient decomposition, it is necessary to set requirements for each sub-process, describing all process parameters, as well as all input and output data. If the technological process consists of several subsystems - stages, it can be developed by several specialists in parallel: each specialist creates a separate process stage according to a predefined and agreed plan (Fig. 1).
- Medical professionals' involvement - the system must be designed with the known process steps described first, so that each doctor does not describe the same process part several times. Also, when creating a new process, it is necessary to verify each process by several specialists, including healthcare and information technology experts. For the sake of system stability, existing processes can only be changed by creating an appropriate request, after which several specialists will check the necessity of changes, as well as validate other processes where this sub-process is already used, so that medical processes are not changed, especially if they are not supposed to.
- Template parameters and their categories. In order to fully implement the stage and fully describe the

operation of medical procedures, it is necessary to use several parameters: patient data recording, symptom recording, used medication recording, event processing, treatment methodology selection, analysis results reading, referrals automatic creation, process workflow change according to criteria. In order for the choice of parameters to be intuitive, the parameter categories must be divided into subcategories until the subcategory becomes self-sufficient and descriptive enough to contain the parameters. The selection of parameters can consist of several steps, because the description of symptoms can contain several parameters: 1) object, 2) object parameter, 3) object parameter states 4) state description.

- Medical process template storage format - the main medical process is divided into stages/sub-processes, where each will be stored as a separate record in the database and is connected to the other processes using identifiers in relational database. However, it could be difficult to store all process related information to be stored in database, so saving process templates in xml format would allow to describe each process in a separate document and describing as many parameters as possible, which will reduce the complexity of the system and facilitate the review of process logic during the verification of processes and their components.
- Use of a medical process template - when a patient comes to a medical institution with a problem, a specialist who works with the medical information system is involved to record patient's first appearance. Then a new diagnostic process is created, which will contain information of patient's examination and is switched to next process when enough data will be collected. Based on new information entered into the system, sub-processes may request additional data from the patient and information about the situation as a whole for further analysis. It is necessary to ensure that the process workflow could be changed during any process control to make it easier to adapt to real situation. Data Analysis layer that was described in centralized cyber-physical information system architecture will be used for the analysis of process templates to assess all possible risk and propose alternative treatment methodology (Fig. 2).

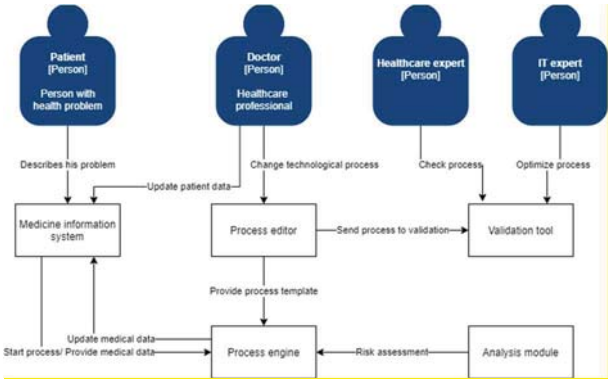

Fig. 2 Medical process control mechanism context

Technological process is complex structure that includes multiple resource usage and multiple guideline and standard considering to process input data and make decision on its base (Fig. 3).

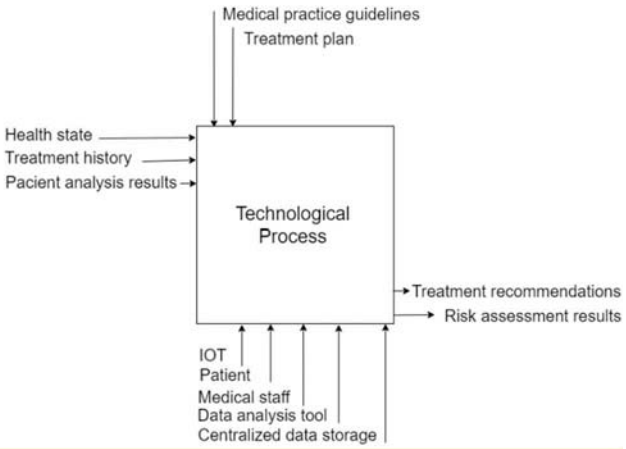

Fig. 3 Technological process context

Process template consists of four main elements, which are used for templates processing:

- Process: Main element that contains process description and workflow plan.
- Function: Part of process that includes logic blocks that could be used in multiple processes.
- Condition: Compares different parameters in order to make decision for next medical process steps.
- Action: Executes predefined function from different categories (Read Treatment History, Manual Entry, Send notification, Read Parameter).

VI. Conclusions and Future Work

Within the framework of the work, the current direction of telemedicine was studied, which will help to improve health care by providing possible and necessary consultations remotely, thus reducing the number of patients in medical institutions and, reducing the chances of getting ill during medical consultation.

The data analysis layer should be used as a separate information system, the main task of which is to be a central data warehouse, without having personal information of patients, with the aim to receive information about all processes and their problems and to be able to predict potential problems in active processes. Such a system must be connected as a separate module so that their functionality can be used by other medical information systems.

Designed information system for medical process control offers medical process template usage, which will help reduce medical errors during patient treatment, and also provide high healthcare quality level. Process template usage could allow configure medical processes as detailed as possible with ability to add control mechanisms where it is necessary, and giving opportunity treatment to be analysed at any step of its process and change it dynamically according to medical standards.

However, despite the advantages of such system usage there might be several problems related with human factor, and the fact that people are not used to use such systems and are not ready yet, so it requires to maintain training environment so specialists could learn continuously. In order to efficiently use process control mechanism, medical staff involvement level must be considered.

Future work concerns deeper analysis of particular mechanisms and develop design of detailed control mechanism structures that would allow to start control mechanism prototype development.

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REFERENCES

[1] A. Litvinenko and A. Aboltins, "Selection and performance analysis of chaotic spreading sequences for DS-CDMA systems," 2016 Advances in Wireless and Optical Communications (RTUWO), Riga, 2016, pp. 38-45, doi: 10.1109/RTUWO.2016.7821852.

[2] S. Gogia, "Fundamentals of Telemedicine and Telehealth", Academic Press, 412 p., 2019.

[3] Telehealth Market 2020 Size, Share, Growth, Trends | Market to Reach $266.8 Billion by 2026 [online]. Fortune Business Insights [accessed 31 August 2020]. Available at: https://www.globenewswire.com/news-release/2020/05/14/2033299/0/en/Telehealth-Market-2020-Size-Share-Growth-Trends-Market-to-Reach-266-8-Billion-by-2026.html

[4] C. Govin, M. Rathod, R. Hummel, "Telehealth Is Here To Stay. What Do You Do Now?" [online]. Vynamic [accessed 31 August 2020]. Available at: https://vynamic.com/insights/telehealth-is-here-to-stay-what-do-you-do-now/

[5] B. Bergman, D. Neuhauser, L. Provost, "Five main processes in healthcare: a citizen perspective", BMJ Qual Saf, Vol. 20, Issue 1, pp. 41-42, 2011.

[6] D. L. Katz, A. Ali, "Preventive medicine, integrative medicine & the health of the public." Integrative Medicine and the Health of the Public: A Summary of the February 2009 Summit, 45 p., 2009.

[7] R. S. Mans, W.M.P. van der Aalst, R.J.B. Vanwersch, "Process Mining in Healthcare Evaluating and Exploiting Operational Healthcare Processes", SpringerBrief in Business Process, 91 p., 2015.

[8] W.H. Gruber, A.C. Powell, J.B. Torous, "The power of capturing and using information at the point of care", Healthcare, Vol. 5, Issue 3, pp. 86-88, 2017.

[9] B.W. Clark, A. Derakhshan, S.V. Desai, "Diagnostic Errors and the Bedside Clinical Examination", Medical Clinics of North America, Vol. 102, Issue 3, pp. 453-464, 2018.

[10] L. Raymond, G. Pare, E. Maillet, A.O. Guinea, M.C. Trudel, J. Maran, "Improving performance in the ED through laboratory information exchange systems", International Journal of Emergency Medicine, Vol. 11, Issue 1, No. 15, 2018.

[11] A.H. Celdran, M.G. Perez, F.J.G. Clemente, G. Martinez Perez, "Sustainable Securing of Medical Cyber-Physical Systems for the Healthcare of the Future", Sustainable Computing: Informatics and Systems, Vol. 19, pp. 138-146, 2018.

[12] A. Skorobogatjko, A. Romanovs, "Kiberfizikālu sistēmu lietošanas strātēģijas izstrāde medicīnas iestādēm.". Master paper. Riga Technical University, 106 p., 2015, In Latvian.

[13] R. Hoyt, "Medical Informatics". Practical Guide for the Healthcare Professional. Third Edition, 334 p., 2009.

[14] Cyber-Physical Systems. Cyber-Physical Systems [online]. [accessed 31 august 2020]. Available at: https://ptolemy.berkeley.edu/projects/cps/

[15] K. Lorincz, B. Chen, G. Challen, A. Chowdhury, S. Patel, P. Bonato, "A wearable sensor network platform for high-delity motion analysis". 7th ACM Conference Embedded Network Sensor Systems, pp. 183-196, 2012.

[16] D. Neiger, L. Churilov, "Dynamic Complexity of Business Systems: Designing Effective Business Processes with System Dynamics", IFAC Proceedings Volumes, Vol. 37, Issue 11, pp. 97-102, 2004. Available at: https://www.sciencedirect.com/topics/computer-science/dynamic-complexity

[17] T. Kanagasabai, N. Thiruchchelav, "Data Verification and Validation Process in the Management System Development", Middle East Journal of Scientific Research, Vol. 25, Issue 5, pp. 902-911, 2017.

[18] A. Chattopadhyay, A. Prakash, M. Shafique, "Secure Cyber-Physical Systems: Current trends, tools and open research problems", Design, Automation & Test in Europe Conference & Exhibition (DATE), pp. 1104-1109, 2017.

[19] F. Pasqualetti, Q. Zhu, "Design and Operation of Secure Cyber-Physical Systems", IEEE Embedded Systems Letters, Vol. 7, Issue 1, pp. 3-6, 2015.

[20] E. Sultanovs, A. Skorobogatjko, A. Romanovs, "Centralized Healthcare Cyber-Physical System's Architecture Development", 57th International Scientific Conference on Power and Electrical Engineering of Riga Technical University (RTUCON), 2016.