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APPLICATION OF INDUSTRY 4.0 MECHANISMS IN MEDICINE ON THE EXAMPLE OF AN INTEGRATED SUPPORT SYSTEM FOR TREATMENT OF OBSTRUCTIVE SLEEP APNEA (OSA)

BARBARA MRZYGŁÓD[1]*, ANDRZEJ OPALIŃSKI[1], KRZYSZTOF REGULSKI[1], MIROSŁAW GŁOWACKI[1], ALEKSANDER KANIA[2], GRAŻYNA BOCHENEK[2], PAWEŁ NASTAŁEK[2], NATALIA CELEJEWSKA-WÓJCIK[2], KRZYSZTOF SŁADEK[2]

[1] AGH – University of Science and Technology, Al. Mickiewicza 30, 30-059 Krakow, Poland
[2] II Chair of Internal Medicine, Faculty of Medicine, Jagiellonian University Medical College Skawinska 8, 31-066, Krakow, Poland
**Corresponding author: mrzyglod@agh.edu.pl*

Abstract

The concept of the 4th Industrial Revolution and the concept of Industry 4.0 are beginning to emerge in many areas of human life and are no longer the domain of the manufacturing industry. Medicine is a special area in which the development of new technologies should bring new opportunities for the diagnosis and treatment of people, as well as the management of medical resources. The paper presents a system for the integration of heterogeneous data sources in the domain of the Obstructive Sleep Apnea (OSA). The concept of the system is described along with its main functionalities, IT architecture and details of the implementation. The data sources and the methods of data acquisition from medical devices integrated with the system are also characterized. The main goal of the system is to facilitate patient's diagnosis and treatment process by integrating the results of the performed medical examinations and analyses. The data source contains clinical interviews, physical examinations, lab tests, and data collected from the devices used to diagnose and monitor patient's parameters during sleep (PSG, CPAP).

Key words: medical data integration, OSA treatment, healthcare support, heterogeneous data source

1. INTRODUCTION

The term *Industry 4.0* defines the fourth industrial revolution, characterized by a significant increase in the degree of automation and data exchange in manufacturing technologies. The term *Industry 4.0* means unifying the real world of production machines with the virtual world of the Internet and Information Technology (IT). People, machines and IT systems automatically exchange information during production - within the factory and within different IT systems operating in the enterprise (Lasi et al., 2014).

The fourth industrial revolution is determined by the development of new technologies such as cloud computing, Big Data and Internet of Things. Most of the solutions that are necessary for its implementation are already available: Internet, standardized data transfer protocols, simulation software, portals to facilitate real-time computational engineering. Revolution 4.0 is a transition to cyber-systems monitoring and managing, often autonomously, physical processes (Jay et al., 2014; Jay et al., 2015).

Although Industry 4.0 was initially targeted at the manufacturing industry (Hannover Fair, 2011), the idea of a fourth industrial revolution and the concept of Industry 4.0 are beginning to emerge and flourish in other areas of human life (figure 1). The medical sector in its widely understood meaning is

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also affected by the development resulting from the fundamental ideas of Industry 4.0.

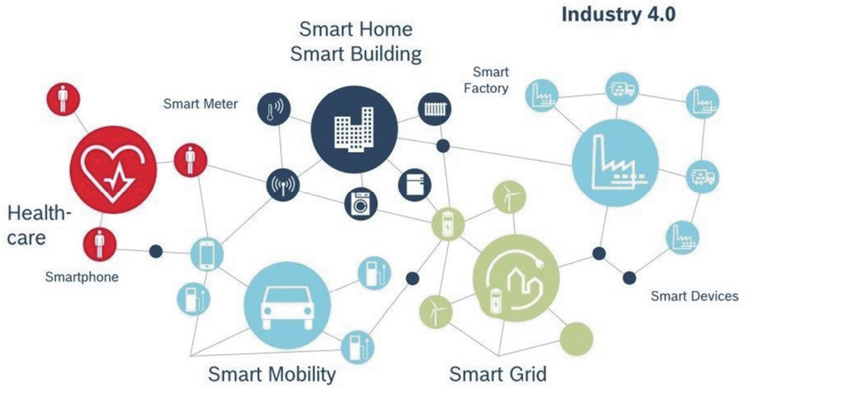

Fig. 1. *Diagram showing interconnections between components of the concept of Industry 4.0 (Piątek, 2017)*

The process of digitization of the Polish medical sector is in the development phase and any attempt aimed at raising its level is well justified. Conducting medical records in electronic form and their standardization will facilitate the exchange of information between entities performing specific tasks in the healthcare system (doctors, administration, devices) and integration of information produced in different field systems. In the long term, a unification of these resources in the field of medicine is expected to provide opportunities for extensive data mining analysis and knowledge base building in specific areas. It will also enable the development of systems for online monitoring of the patients' condition.

The staff of the Department of Computer Science and Modeling, AGH University of Science and Technology in Krakow, acting on behalf of and in cooperation with the Clinical Department of Pulmonology of the University Hospital in Krakow, has developed and implemented an integrated medical information system in the field of OSA. The creation of a central database with a wide range of clinical information enabling prospective surveillance of patients with OSA is part of the current trends observed in Industry 4.0 process.

2. OBSTRUCTIVE SLEEP APNEA (OSA)

Obstructive Sleep Apnea (McEvoy et al., 2014; Saaresranta et al., 2016) is a disease caused by repeated episodes of the cessation of breathing (sleep apnea) or shortness of breath (hypopnoea). The cessation of breathing repeats itself from a dozen to several dozen times during each hour of sleep, causing numerous harmful consequences, including fatigue, concentration problems and hypertension (Marrone et al., 2016; Jennum et al., 2016).

Diagnosing the disease, assessing its severity, and recommending proper treatment requires the attending physician to perform a series of tests. The tests include, but are not limited to, clinical interviews, physical examinations, laboratory tests, pulmonary function tests (Tkacova et al., 2014; Kent et al., 2014). Basic examinations also include sleep tests performed on devices such as PolySomnoGraphs (where the patient's condition is monitored by a set of sensors determining, among others, oxygen content in blood, heart rate, nasal and mouth airflow, snoring, electroencephalogram, limb movement, etc.) and a CPAP (Continuous Positive Airway Pressure) air pump (where the digital system recording pump operating parameters is installed and stored on SD cards). The data collected during numerous studies have a very heterogeneous nature and form (Passali et al., 2012; Hedner et al., 2011). They are also characterized by a high degree of dispersion. Some of the results are stored in the hospital electronic databases, some of the results in form of a paper documentation, while others are stored in dedicated databases used together with the research facilities.

Storing this information in an integrated form within one system will be an excellent support for the physician in the process of diagnosis and treatment of patients. Additionally, gathering in a single database all the characteristics of many patients will allow for their advanced analysis (data mining) in search of patterns and relationships.

3. THE INTEGRATED MEDICAL DATA SYSTEM IN OSA

The main goal of the system is to improve the treatment of patients with sleep disorders by:

- streamlining the work of physicians through integration of research and treatment data into one system,
- creating fast, easy and secure access to patient data for all authorized medical staff of the clinic,
- implementation of automatic calculation of the patient's basic disease indicators based on the given algorithms and patient data, and also

– providing the export of selected data and making advanced external analysis.

3.1. Data sources

The process of designing the system architecture was preceded by analysis and identification of medical parameters, which should be systematically fed to the system as highly relevant for the diagnosis and treatment of patients. Their analysis showed very high diversity in terms of the type, shape and dispersion (Opalinski et al., 2017).

Some of the parameters originating from the clinical history, physical examinations, diagnosed cardiovascular diseases, malfunctioning of the respiratory system, medicines taken, etc. are obtained during the patient interview and are stored in the patient's medical records.

Most of the parameters are the results of patient tests carried out on hospital diagnostic equipment (PolySomnoGraph; PSG) and CPAP air pumps. In structured form but in various formats of the electronic version they are stored in dedicated databases for use along with the research devices; shortened report printouts are also stored in the form of paper documentation.

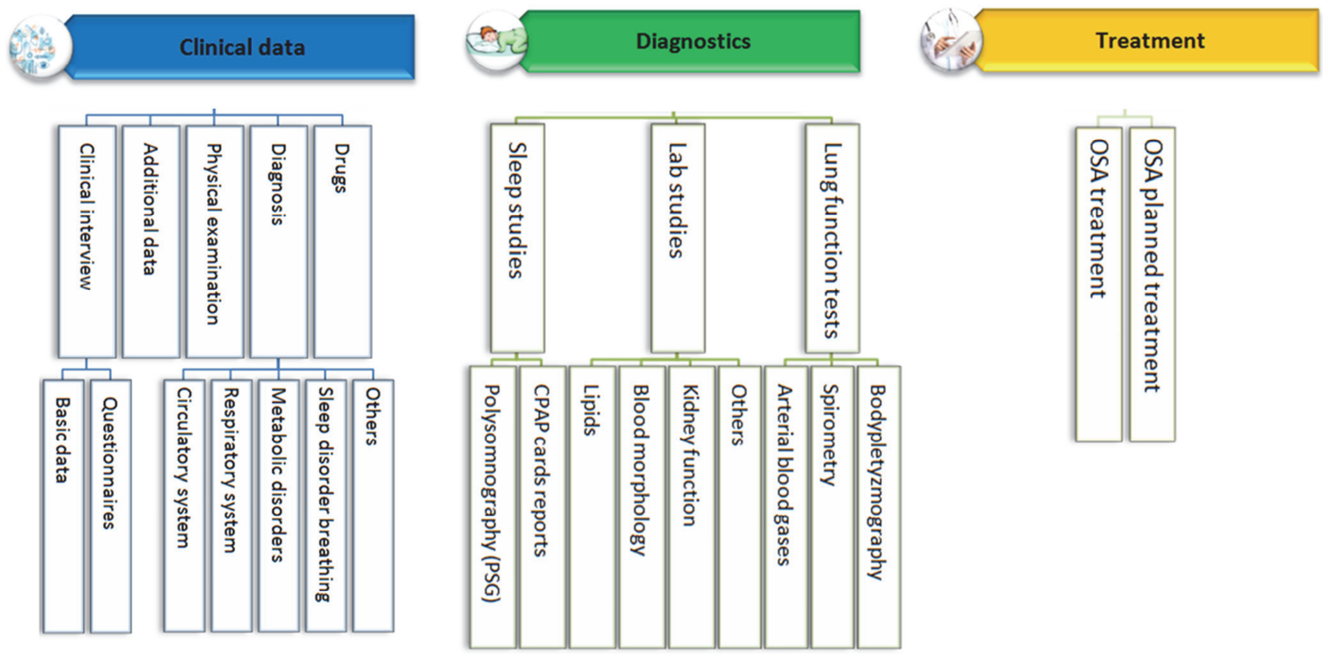

Fig. 2. Data source for the system.

Other groups of parameters are the results of laboratory tests (e.g. lipidogram, blood morphology, renal function tests, etc.), arterial blood gas tests and lung function tests (e.g. spirometry, body plethysmography). These results are stored in paper medical records.

Altogether 468 parameters were identified, of which 213 were the results of clinical trials, laboratory tests, medical recommendations, etc., while 255 were data supplied by PSG and CPAP.

The identified parameters were divided into three main categories:
– clinical data,
– data from research and diagnostics, and
– medical recommendations.

In each category, specific groups of parameters were distinguished, and their list is shown in figure 2.

3.2. Architecture of the proposed solution

The IT architecture of the presented system is based on the thin-client model, where server integrating the heterogeneous data sources is the central part of the system. The general model of the system with its main components is shown in figure 3. The server access is provided to authenticated users via a web browser application. Another key component of the system is an application that allows parsing and extraction of information from reports generated by devices used to study patients' dreams. Based on the PDFParser library (for hospital monitoring devices) and RTFExtractorKit (for patient mobile devices), the extraction of information is performed and the extracted information is sent to the central server.

An additional functionality of the system is the ability to export the collected data to the CSV format, which is used for later advanced analysis and data processing.

pital staff), patient monitoring devices (CPAP and PSG) and a separated dedicated application, used by a hospital personel, which performs parsing and data export from the devices.

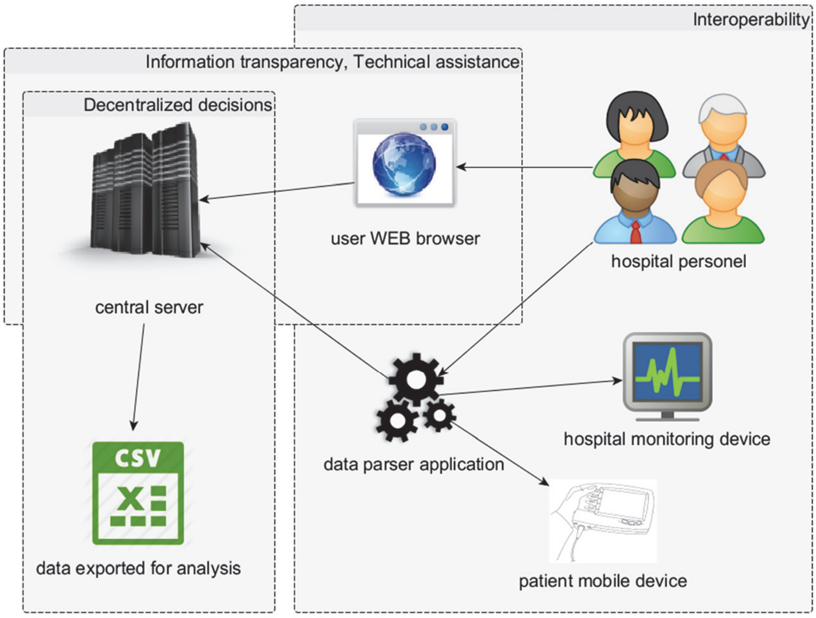

Fig. 3. General model of the system mapping the fundamental assumptions of Industry 4.0

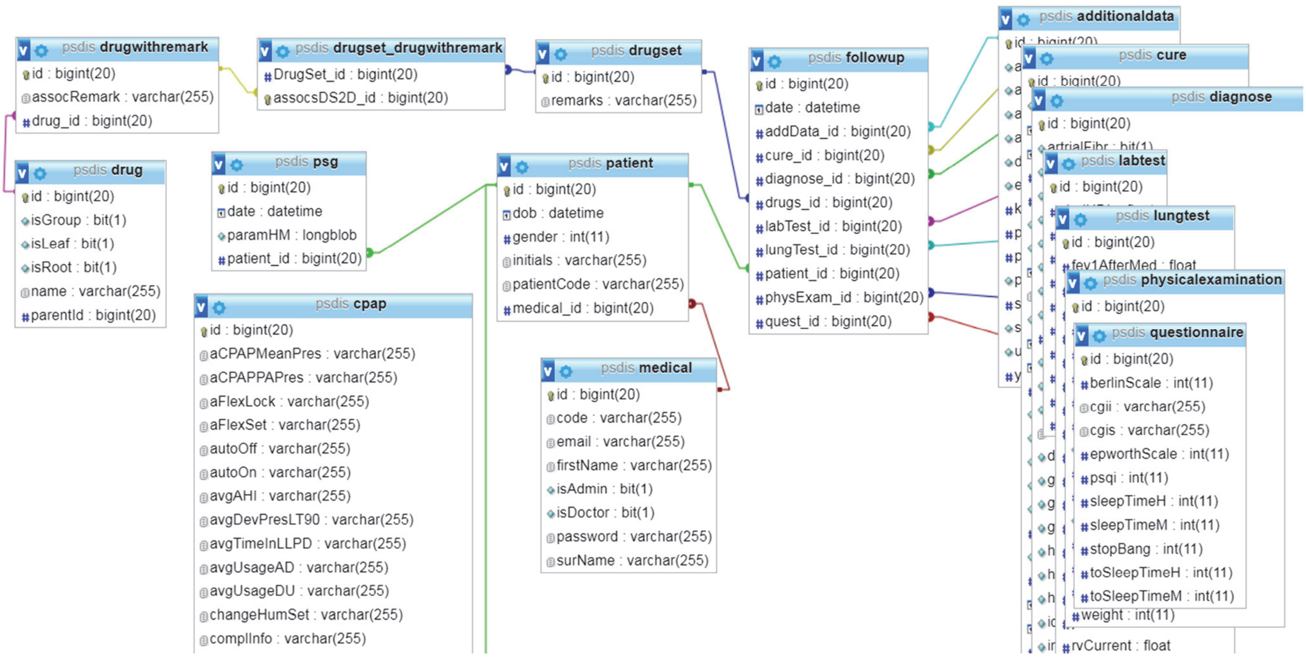

Fig. 4. A universal data model that implements the information transparency concept

Figure 3 also shows which elements of the system fulfill the main assumptions of the Industry4.0 concept.

The concept of *interoperability*, i.e. the acquisition of information from a variety of sources, is implemented in a portion comprising the graphical interface of the system (the data entered by the hos-

The concept of *information transparency*, i.e. a virtual model of the simulated process environment supplemented by information from the sensors, is implemented through a universal data model based on the MySQL database engine. The structure of this model is shown in figure 4.

The concept of *technical assistance*, i.e. user support in the decision making process, is based on a server component that calculates selected disease indicators informing the physician of potential abnormalities and disorders in the patient's condition. This information is based on GUI system.

The last element of the Industry4.0 concept, i.e. *decentralized decisions*, consists again of a server component that stores data on the patients' condition and their treatment process, as well as the exported patient-specific CSV reports, based on which hospital staff can perform advanced data analysis.

The developed system has implemented mechanisms to automatically calculate the basic patient disease indicators based on the developed algorithms and patient data. At present, the system calculates the following indicators:

- number of pack-years,
- BMI index,
- lipid disorders,
- metabolic syndrome,
- cardiovascular risk - SCORE algorithm,
- calculation of percent parameters of spirometry:
  - FEV1% of the reference value,
  - FVC% of the reference value,
  - FEV1 / FVC ratio,
  - RV% of the reference value,
  - RV / TLC ratio.

laboratory is responsible for laboratory tests and the lung examination. Sleep tests are carried out by the hospital staff under medical supervision on devices available in the hospital. An example of the questionnaire developed in the main system interface is shown in figure 5.

System security is ensured through mechanisms: access via and using login and password, securing access to the server only for a limited list of IP addresses.

4. PRELIMINARY RESULTS OF DATA ANALYSIS

Risk factors affecting Obstructive Sleep Apnea (OSA) can in themselves constitute the cause of death for patients, particularly for cardiovascular disease. Searching for connections between various symptoms and medical indicators may enable proper treatment of important risk factors. These units are, among others ischemic heart disease, diabetes, chronic kidney disease, etc. Integrated data from a variety of sources, for example: clinical questionnaires and sleep testing devices as polysomnographers (PSGs) or reports from SD cards (CPAP) allow for multidimensional analyzes to search for unknown associations. The discovery of the relationship between clinical history and sleep quality indicators will help to better diagnose Obstructive Sleep Apnea.

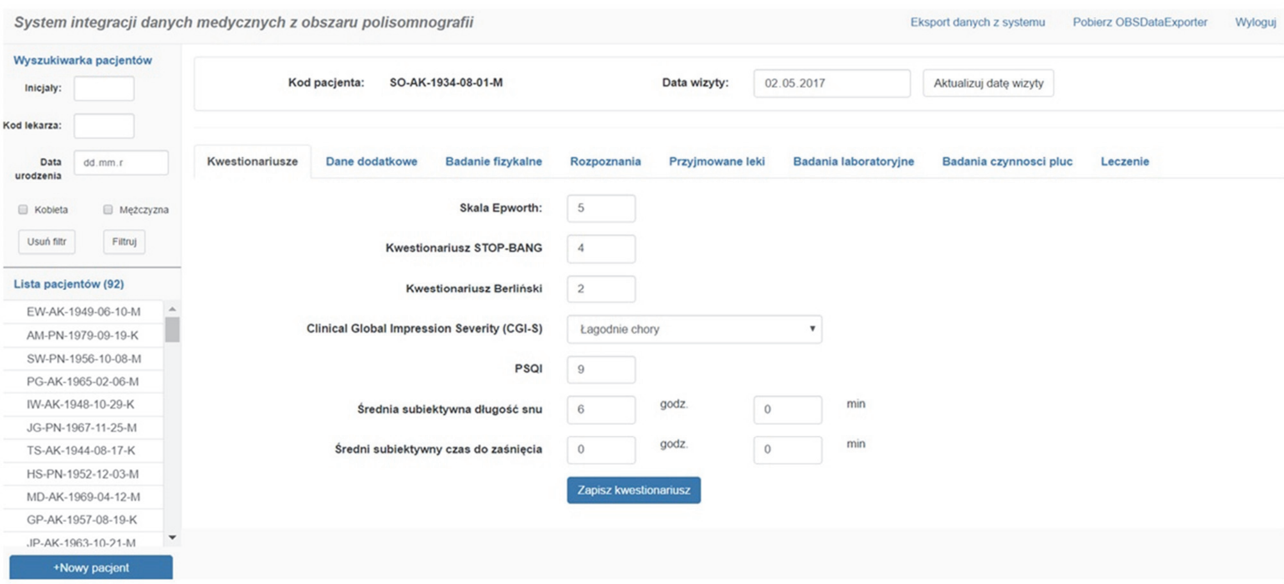

Fig. 5. An example of forms developed in the system

Data entry into the central database of the system is done through the developed forms. Each form consists of data grouped according to the scheme presented in figure 2. The leading physician is responsible for the diagnosis and the interview, the

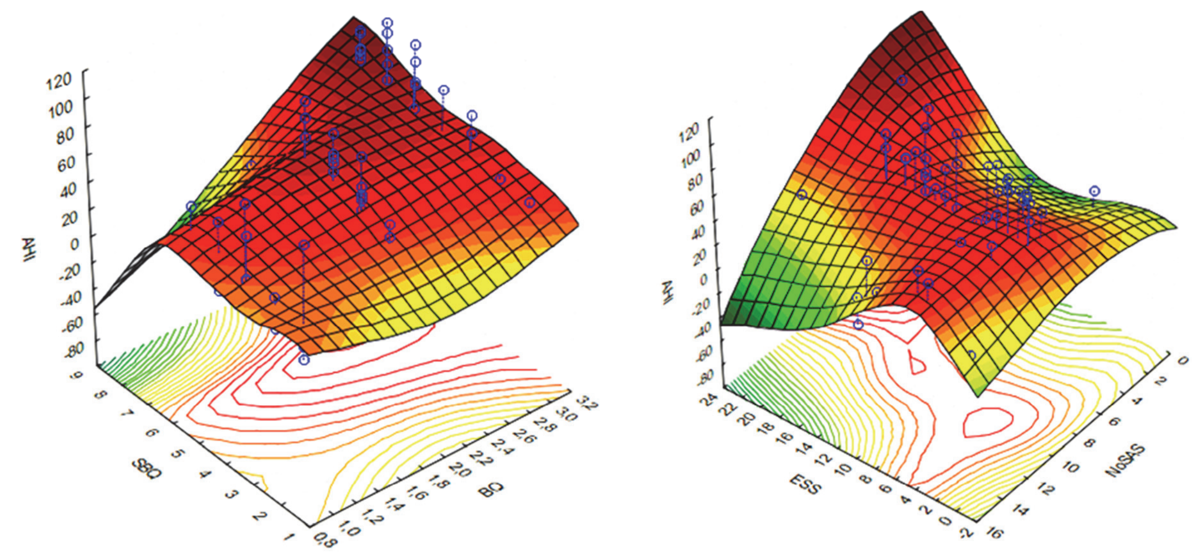

Fig. 6. *Predicting AHI using different questionnaires*

The most important indicator describing the advancement of OSA is the Apnoea-Hypopnoea Index (AHI). The purpose of the preliminary analysis was to try to identify couples or more numerous questionnaire collections that would enable more accurate AHI forecasting. Inclusion of successive variables in the predictive model allows improving the matching of results in groups marked by a different scale as "heavy". This allows for double diagnosis of risk-bearing cases using different questionnaires carrying different substantive information. Preliminary results suggest that the appropriate selection of measuring scales will improve the classification, but at present the model predicts only severe cases quite well, in other cases it is quite a mistake. False-negative = 17/93 (18.2%); False-positive = 14/93 (15%); Valid 62/93 classification = 67%.

A key factor in the improvement of predictive models is the extension of the database about new patients and the performance of expiration tests in the search for groups of patients with similar disorders depending on the diagnosed risk factors.

5. SUMMARY AND PERSPECTIVES FOR FURTHER DEVELOPMENT

This paper presents an IT system that has been designed and implemented to improve the treatment of patients with sleep disorders. The main advantages of the system are aggregation of data from various sources (diagnostics, medicines, lab-tests, medical history) and its integration with devices for monitoring sleep parameters of patients. The system was applied at the Department of Pulmonology of the University Hospital in Krakow and is used in the process of diagnosis and treatment of patients. It has significantly improved the work of the hospital staff and facilitated their access to previously distributed patient data.

The system implements all basic assumptions of the Industry 4.0 concept, including interoperability, technical assistance, distributed decisions and information transparency. This fact shows that the concept, although treated as strictly industrial, is also applicable in other areas.

One of the plans for further development of the system is to use it for advanced data analysis algorithms: classification methods, expert and agent systems that could further assist medics by predicting possible medical conditions based on historical and current data collected in the system and disease models developed by the medical team. The system is a platform and a perfect starting point for research, combining statistical and analytical methods with medical models and real data stored in system resources.

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ZASTOSOWANIE MECHANIZMÓW INDUSTRY 4.0 W MEDYCYNIE NA PRZYKŁADZIE ZINTEGROWANEGO SYSTEMU WSPOMAGAJĄCEGO LECZENIE W DZIEDZINIE OBTURACYJNY BEZDECH SENNY (OBS)

Streszczenie

Idea czwartej rewolucji przemysłowej oraz koncepcja Industry 4,0 zaczynają pojawiać się w wielu obszarach życia ludzkiego i nie są już domeną tylko przemysłu wytwórczego. Medycyna jest szczególnym obszarem, w którym rozwój nowych technologii powinien przynieść nowe możliwości diagnozowania, leczenia ludzi a także zarządzania zasobami medycznymi.

W pracy przedstawiono system integracji heterogenicznych źródeł danych w dziedzinie Obturacyjnego Bezdechu Sennego (OBS).

W artykule opisano koncepcję systemu, jego główne funkcjonalności, architekturę i technologię IT oraz kilka szczegółów dotyczących jego implementacji. Scharakteryzowano także źródła danych i metody pozyskiwania danych ze zintegrowanych z systemem urządzeń medycznych: PolySomnoGraph (PSG) and CPAP air pumps.

Głównym celem tego systemu jest ułatwienie diagnozowania i leczenia pacjenta poprzez integrację wyników przeprowadzonych badań i analiz medycznych. Źródła danych systemu pochodzą z: wywiadów klinicznych, badań fizykalnych, testów laboratoryjne oraz dane zebrane z urządzeń służących do monitorowania parametrów snu pacjenta (PSG, CPAP).

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