JOURNAL OF MODERN SCIENCE
SPECIAL ISSUE
3/57/2024
www.jomswsge.com
DOI: doi.org/10.13166/jms/191255

JAN SIKORA
WSEI University in Lublin, Poland
ORCID iD: orcid.org/0000-0002-9492-5818

BARBARA STEFANIAK
Netrix S.A., Poland
ORCID iD: orcid.org/0000-0001-6555-8230

DARIUSZ KASPEREK
WSEI University in Lublin, Poland
ORCID iD: orcid.org/0000-0002-8456-3008

JOANNA GIRZELSKA
WSEI University in Lublin, Poland
ORCID iD: orcid.org/0000-0002-5537-0987

IMPLEMENTATION OF ELECTRICAL TOMOGRAPHY IN A MEDICAL MEASUREMENT SYSTEM FOR INNOVATIVE IMAGING AND AREA MONITORING

ZASTOSOWANIE TOMOGRAFII ELEKTRYCZNEJ W MEDYCZNYM SYSTEMIE POMIAROWYM DO INNOWACYJNEGO OBRAZOWANIA I MONITOROWANIA OBSZAROWEGO

Abstract

LETS (Lung Electrical Tomography System) is an innovative medical system enabling comprehensive heart and lung function monitoring. It utilizes advanced techniques such as electrical impedance tomography (EIT), body surface potential mapping (BSPM), and electrical capacitance tomography (ECT) to provide accurate information about physiological parameters. The LETS system allows one-time examinations and continuous monitoring 24 hours a day. Remotely measuring and monitoring parameters such as the electrical activity of the heart muscle, blood flow, blood pressure, pulse, and lung aeration enables rapid identification and intervention in case of abnormalities. The system also allows for the detection of cardiac arrhythmias and other heart disorders, as well as the assessment of lung respiratory capacity and optimization of ventilation strategies. However, it's important to note that the LETS system has some limitations. For example, it may not be suitable for patients with certain pacemakers or other implanted devices. Overall, LETS represents a breakthrough in medical imaging, opening up new possibilities in diagnosing and monitoring heart and lung diseases. Its integration may contribute to improving patient care and increasing the effectiveness of medical interventions.

Streszczenie

LETS (Lung Electrical Tomography System) to innowacyjny system medyczny, który umożliwia kompleksowe monitorowanie funkcji serca i płuc. Wykorzystuje on zaawansowane techniki, takie jak elektryczna tomografia impedancyjna (EIT), badanie potencjału powierzchni ciała (BSPM) oraz elektryczna tomografia pojemnościowa (ECT), aby dostarczyć dokładnych informacji na temat parametrów fizjologicznych. System LETS pozwala zarówno na jednorazowe badania, jak i ciągłe monitorowanie przez 24 godziny na dobę. Dzięki zdalnemu pomiarowi i monitorowaniu takich parametrów jak aktywność elektryczna mięśnia sercowego, przepływ krwi, ciśnienie krwi, tętno czy upowietrznienie płuc, umożliwia szybką identyfikację i interwencję w przypadku nieprawidłowości. System pozwala także na wykrywanie arytmii serca oraz innych zaburzeń sercowych, a także ocenę pojemności oddechowej płuc i optymalizację strategii wentylacji. Ogólnie rzecz biorąc, LETS reprezentuje przełom w dziedzinie obrazowania medycznego, otwierając nowe możliwości w diagnostyce i monitorowaniu chorób serca i płuc. Jego integracja może przyczynić się do poprawy opieki nad pacjentami i zwiększenia skuteczności interwencji medycznych.

Keywords: *Electrical impedance tomography, Electrical capacitance tomography, Body surface potential mapping, Postgres database, Artificial neural networks*

Słowa kluczowe: *elektryczna tomografia impedancyjna, elektryczna tomografia pojemnościowa, bazy danych postgres, sztuczne sieci neuronowe*

Introduction

Medical imaging is a crucial element of modern healthcare, providing valuable insights to physicians about the structure and function of various organs and tissues. One innovative approach in this field is developing a medical measurement system designed for spatial monitoring and imaging (LETSWEB). These systems are designed to provide precise and comprehensive visualization of specific anatomical areas, facilitating diagnosis and monitoring of pathological conditions. In this article, we explore the concept and applications of this system, which is dedicated to innovative imaging and spatial tracking.

The LETSWEB platform is a distributed web-server system for collecting, processing, analysing, and interpreting measurement data. It consists of several functional modules, including:

- Web-server system.
- Database of measurement results.
- Collection of algorithms for data processing, analysis, and visualisation.
- Expert system.
- The main components of the system include:
- Database system.
- Module for processing measurement and medical data.
- Module for data analysis and interpretation.
- User module.

Measurement devices provide measurement results, which are collected in the measurement database. Subsequently, the data is processed and analyzed using dedicated numerical tools. Additionally, the system utilizes medical data from healthcare facilities such as hospitals as an additional source of information.

The processed data results and medical data are transmitted to the Interpretation and Inference Module. There, the system compares them with information stored in the Medical Knowledge Base, interprets and infers possible causes of the situation, and formulates a diagnostic proposal. However, it should be emphasized that this is only a diagnostic proposal, which the attending physician can then confirm or reject based on their knowledge and experience. Feedback information is added to the medical knowledge base to confirm the diagnosis, enabling further system improvement.

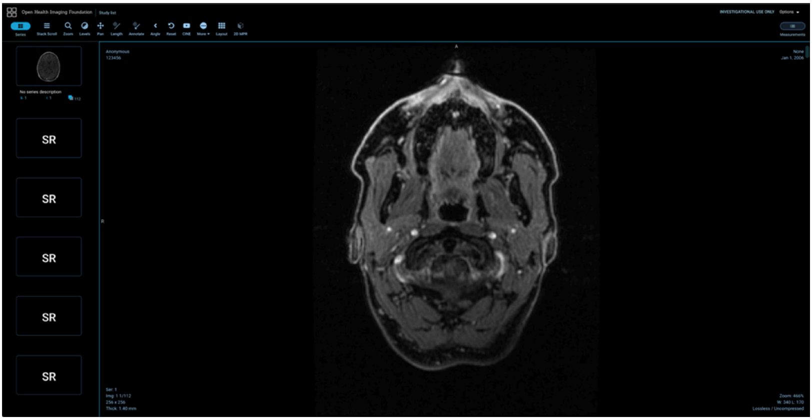
The main components of the system

The Postgres database stores all user data and data associated with the operation of the system's CMS layer. Data partitioning: For security reasons and to avoid excessive load, data is divided according to different user groups and functions: patient data, doctor data, administrator data, and CMS data. Each of these data groups is stored on a separate Postgres server. Such partitioning helps manage load and increases data security. Security measures: Passwords for the database servers are stored in a separate location using the secrets functionality of the Docker tool. This ensures that the service-building file does not contain passwords, further enhancing system security.

Medical data handling module: This key system element handles medical data from two sources: DICOM files and measurements collected from the vest. DICOM files: DICOM format files provided by the patient are stored in a specially designed database. This database communicates using REST API and Python language library. A table linking these two values has also been created to associate HashId in Orthanc with identifiers in the rest of the system.

Partial data: These data result from processing input data but cannot yet be used for visualization. They are stored in the MinIO object database, which allows data to be stored in practically any format. Additionally, a table has been created in the relational database to store relationships between files in MinIO and patient identifiers to which these data belong. DICOM viewer: The open-source *OHIF* viewer was decided to allow physicians to view DICOM files, which offers many valuable tools. The viewer has been implemented into LETSWEB using a frame tag. This ensures that the files do not leave the server, and the physician receives the full functionality of the viewer Figure 1.

Figure 1. *Window browser DICOM*



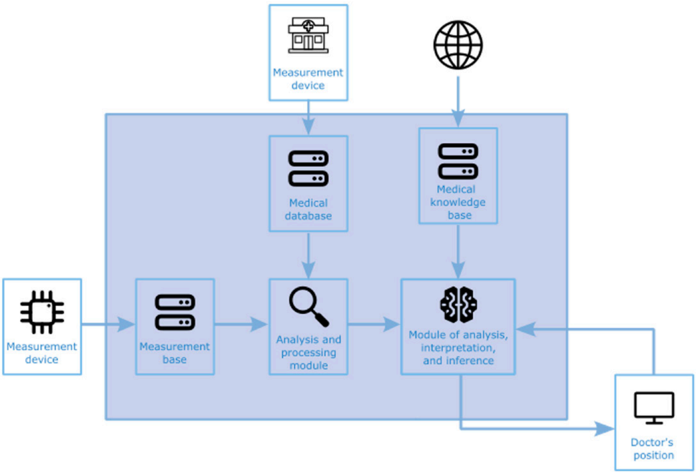
Application of IoT in healthcare: Healthcare is one of the most attractive areas for IoT application. This technology has the potential to be used in various medical fields, such as remote monitoring, fitness programs, monitoring individuals with chronic diseases, and healthcare for the elderly. It is predicted that the development of wireless technologies with increasingly more comprehensive coverage and faster data transfer will enable rapid data transmission, thereby contributing to quicker diagnosis.

Diagnosis and decision-support systems: There are various diagnoses, such as probabilistic, Bayesian, pattern recognition, and causal or deductive. Each requires complex decisions that the system must make; therefore, cloud computing or supercomputers are essential for physicians' assistance. Many techniques can support clinical decision-making, such as neural networks, systems based on rough set theory, conditional probability, fuzzy systems, and clinical algorithms.

Artificial neural networks: Artificial neural networks have been created as models that mimic the functions of the nervous system. They are capable of learning, parallel processing of information, processing incomplete data, generating approximate results, and self-analysis. Neural networks are built by connecting neurons, which form a network. For self-analysis and self-diagnosis, it is necessary to use multilayer neural networks that contain so-called hidden layers. Application of neural networks in medicine: Neural networks are used in various fields of medicine, such as patient condition recognition based on symptoms, analysis of medical images, filtering from signal devices, and searching for regularities in medical databases. An example of such a system, based on the application of neural networks, is Watson Healthcare, which IBM produced.

Analytical engine: The analytical engine serves in the system as a tool for analyzing medical data. The medical data analyzed by the engine will provide suggestions to the physician for faster diagnosis. Decision support in medicine using already built-in systems is becoming increasingly important in the face of advancing technology. Systems based on self-detection and self-analysis, which will analyze medical data and detect medical pathologies, can be helpful for physicians.

Figure 2. *An example of how the analytical engine for ROI detection works*



Detection of pathological changes: The accuracy of detecting changes is crucial for precisely analysing pathological disorders. Due to tissues' relatively high conductivity, imaging of them can be achieved using measurement devices. Algorithms can process bioelectrical signals to obtain reconstructions, which can then be filtered, segmented, and analyzed. This way, the analytical engine can detect relevant regions of interest (ROIs) with pathological abnormalities (Goncalves, 2021).

Limitations of a single imaging modality: However, relying solely on one modality may prove insufficient. Imaging methods of the human body using electrical tomography have low resolution, which may lead to not detecting all pathological changes in the examined organ after obtaining the final result from machine learning (Goncalves, 2021). Expanded database for the analytical engine: Therefore, the analytical engine needs an extensive database of pulmonary and cardiac disorders obtained using various imaging methods such as CT, MRI, etc.

Additional data and learning algorithms: This will give learning algorithms a more significant knowledge base about pathological lung changes. This, in turn, will enable the algorithms to determine regions of interest (ROIs) through self-detection, i.e., places where pathological changes are exactly located for a given patient (Shimazaki, 2022). Patient monitoring using electrical tomography: Subsequently, during patient monitoring using electrical tomography, it will be possible to detect whether visible changes have occurred in the ROIs while using the measurement device.

The user module is designed with three groups of users in mind, which differ in their level of permissions:

- Patient: This account has the lowest permissions, only allowing the view of scheduled examinations in the calendar and personal data. There is no possibility to add any records.
- Doctor: This account offers more capabilities, such as managing patients (adding new accounts, editing existing ones), conducting examinations (borrowing and returning devices, viewing the list of completed examinations and visualizations), searching for patients by first or last name, adding scheduled examinations to the calendar, and viewing personal data.
- Administrator: This account, following the assumptions of Unix systems, has access to all system functionalities. This includes all functions available to the doctor, adding doctors and other administrators, managing devices (adding, editing, lending to doctors), and accessing historical data regarding edited records.

One-time examinations and 24-hour monitoring of heart and lung function parameters

LETS is a mobile tomographic imaging and area monitoring system that utilizes nodal potential maps. The measurement device (vest) uses techniques based on electrical impedance tomography (EIT) and body surface potential mapping (BSPM). Additionally, electrical capacitance tomography (ECT) visualises the spatial distribution of electrical conductivity within the examined volume. The image is reconstructed based on mutual capacitance measurements between surface electrodes surrounding the examined volume. This technique is characterized by very high measurement frequency, allowing imaging of dynamic phenomena.

Studies based on the BSPM technique enable noninvasive monitoring of the electrical activity of human organs without radiation emission. Techniques such as ECG, electromyography, and electroencephalography (EEG) are based on this technique. The most straightforward method for hemodynamic monitoring is impedance cardiography (ICG), allowing assessment of both cardiac output (CO) and other hemodynamic parameters, such as thoracic fluid content (TFC), systemic vascular resistance (SVR), and heart rate (HR).

The LETS system will remotely measure and monitor essential parameters of heart and lung function, such as electrical activity of the heart muscle, blood flow, blood pressure, pulse, thoracic impedance and its changes, lung aeration including PEEP and ΔEELV, and relative electrical conductivity, as well as patient position during examination. Heart muscle activity based on changes in nodal potential maps. During heart function analysis, the first parameter that can be read is the heart rhythm, i.e., the number of beats per minute, known as the pulse. Analysis of intervals between individual heart cycles allows the determination of R-R intervals – their excessive variability may indicate cardiac arrhythmias.

A monitoring vest placed on the patient's chest using electrode arrays allows precise detection of any abnormalities in the heart's electrical activity, enabling detection of conditions such as myocardial infarction. Additionally, visualization of changes in the conduction of cardiac electrical signals in areas not detectable in standard 12-lead ECGs can be achieved. Cells that do not receive adequate blood supply become oxygen-deprived, altering their mechanism and pace of work, which can be observed through parameters deviating from the norm in the electrical signal flow. Algorithms can detect pre-infarction states and alert medical services to intervene appropriately and prevent a heart attack. The proposed solution can also diagnose the state after myocardial infarction – damaged cardiomyocytes are not replaced by muscle cells but only by connective tissue. This negatively affects the heart's performance capabilities, and from a diagnostic point of view, it changes the way electrical stimulation flows, measured in the BSPM technique. Using a matrix consisting of multiple electrodes, as in the diagnostic vest, allows the diagnosis of numerous heart function disorders—cardiac arrhythmias based on changes in nodal potential maps. The BSPM technique is very suitable for diagnosing heart rhythm disorders. It involves measuring electrical potential directly on the skin of the patient, significantly expanding the method used in electrocardiography (ECG) examination. The greatest advantage is collecting information from electrodes placed all over the patient's chest.

The LETS measurement device allows for obtaining data from areas traditionally located electrodes – and using them similarly to routine diagnostics, subjecting them to analysis and drawing conclusions from a traditional ECG, but offering much more. In the BSPM area, the heart can be imaged in a full 360° range, as we have electrodes from the front and back. Sides of the chest, and this imaging is performed from several rows of electrodes – some placed higher, others lower, covering the heart from the atria, through the ventricles, to the apex. It will be easier to detect abnormalities in the conduction of impulses of the heart's control system and detect changes within the heart muscle in different locations.

Respiratory lung capacity based on electrical tomography measurements. Obtaining lung capacity depends on the frequency at which measurements were taken, as soft lung tissue contains membranes with high relative permeability. Suppose lung tissue resistance is measured at a sufficiently high frequency to allow current to pass through all cell membranes. In that case, the lungs consist only of two elements: air with almost infinite resistivity and condensed matter with nearly uniform resistivity, determined by the resistivity of intracellular and extracellular fluids. To estimate lung resistance at frequencies above 2 MHz, values obtained for frequencies from 2 to 768 kHz (24 frequencies) were first fitted to Cole's equation using a method described by Waterworth et al. (Vargas-Luna, 2024).

Lung impedance is analyzed using electrical tomography. In EIT tomography, individual measurement frames collected during a several-second measurement are analyzed. These frames are then reconstructed and passed to interpreting algorithms.

PEEP (Positive End-Expiratory Pressure) based on electrical tomography measurements. Typically, the EIT technique is used in medicine for lung imaging and examination. Lungs are organs that dynamically change their volume through inhalation and exhalation processes. Lungs show greater resistance when properly aerated, with a median lung resistance of 157 Ω cm, a maximum value (during maximum inhalation) of 300 Ω cm, and a minimum value of 100 Ω cm. PEEP prevents excessive lung emptying during exhalation. It is a component of both conventional mechanical ventilation, non-invasive nasal ventilation, and support of the patient's own breathing with CPAP (Heines, 2023).

Relative electrical permeability is based on electrical tomography measurements (Wójcik, 2022). We can maintain different resistance to current flow by applying impedance to tissues. At the same time, these results are not absolute and may vary depending on ambient temperature, blood pressure, etc. Here are the sample electrical resistivity values for various tissues:

- Lung during exhalation: 12.5 Ωm
- Lung during inhalation: 25 Ωm
- Blood (50% hematocrit): 1.4-1.7 Ωm
- Muscles/coronary vessels: 2.5-5 Ωm
- Skeletal muscles: 15-5 Ωm
- Liver: 8.3 Ωm
- Fat: 10-50 Ωm
- Bone tissue: 160 Ωm

Conclusions

The LETSWEB platform represents an innovative medical imaging and spatial monitoring approach, offering a comprehensive data collection, processing, and analysis system. With its distributed web-server architecture and dedicated modules, LETSWEB enables precise visualization and interpretation of measurement data, facilitating diagnosis and monitoring of pathological conditions. Key components of the LETSWEB system include a database system, data processing and analysis modules, and a user interface for interaction with healthcare professionals. Measurement devices collect data, which is then processed and analyzed using numerical tools. Medical data from healthcare facilities further enrich the system, providing additional context for interpretation.

The Interpretation and Inference Module plays a crucial role in the diagnostic process, comparing measurement results with information stored in the Medical Knowledge Base to formulate diagnostic proposals. However, these proposals are subject to confirmation by attending physicians, who rely on their expertise to validate the findings. Integrating LETS (Local Electrode Tomography System) into medical practice heralds a significant advancement in diagnostic capabilities, particularly cardiovascular and pulmonary health monitoring. LETS employs a multifaceted approach, leveraging techniques such as electrical impedance tomography (EIT), body surface potential mapping (BSPM), and electrical capacitance tomography (ECT) to provide comprehensive insights into physiological parameters.

One notable feature of LETS is its ability to conduct one-time examinations and continuous 24-hour monitoring of heart and lung function parameters. This capability is precious in identifying dynamic physiological changes and detecting abnormalities early on. LETS facilitates proactive intervention and management of cardiac and respiratory conditions by remotely measuring and monitoring key parameters such as the electrical activity of the heart muscle, blood flow, blood pressure, pulse, thoracic impedance, and lung aeration. The system's versatility extends to its diagnostic capabilities, allowing for detecting various cardiac arrhythmias and abnormalities in heart function. Monitoring vests equipped with electrode arrays enable precise detection of irregularities in the heart's electrical activity, including those that may not be detectable with standard ECGs. Moreover, LETS offers insights into post-myocardial infarction states, providing clinicians with valuable information for patient management and risk stratification.

In the realm of pulmonary health, LETS enables the assessment of respiratory lung capacity and monitoring parameters such as Positive End-Expiratory Pressure (PEEP) to optimize ventilation strategies. LETS provides a non-invasive means of evaluating lung function and detecting abnormalities in ventilation dynamics using electrical tomography measurements. Overall, LETS represents a paradigm shift in medical imaging and monitoring, offering clinicians a powerful tool for early detection, diagnosis, and management of cardiovascular and pulmonary conditions. Its integration into clinical practice can potentially improve patient outcomes and enhance personalised healthcare delivery.

References

Abdou, M. A. (2022). 'Literature Review: Efficient Deep Neural Networks Techniques for Medical Image Analysis'. Neural Computing and Applications 34, no. 8 (1 April 2022): 5791–5812. https://doi.org/10.1007/s00521-022-06960-9

Goncalves, J. P. N., De Waal, G. M., Page, M. J., Venter, C., Roberts, T., Holst, F., Pretorius, E., Bester J., (2021). 'The Value of Detecting Pathological Changes During Clot Formation in Early Disease Treatment-Naïve Breast Cancer Patients'. Microscopy and Microanalysis 27, no. 2 (April 2021): 425–36. https://doi.org/10.1017/S1431927621000015

Goncalves, J. P. N., De Waal, G., Page, M.J., Venter, C., Roberts, T., Holst, F., Pretorius, E., Bester, J., (2021). 'The Value of Detecting Pathological Changes During Clot Formation in Early Disease Treatment-Naïve Breast Cancer Patients'. Microscopy and Microanalysis 27, no. 2 (1 April 2021): 425–36. https://doi.org/10.1017/S1431927621000015

He, B.,(2004). *Modeling and Imaging of Bioelectrical Activity Principles and Applications*.

Kłosowski, G., Rymarczyk, T., Wójcik, D., Skowron, S., Cieplak, T., Adamkiewicz. P., (2020) *'The Use of Time-Frequency Moments as Inputs of LSTM Network for ECG Signal Classification'. Electronics 9. https://doi.org/10.3390/electronics9091452.*

Heines, S. J. H., Becher, T. B., Van der Horst, I. C. C., Bergmans, D. J. J, (2023). 'Clinical Applicability of Electrical Impedance Tomography in Patient-Tailored Ventilation: A Narrative Review'. Tomography 9, no. 5 (October 2023): 1903–32. https://doi.org/10.3390/tomography9050150

Macfarlane, P. W., (2010). *Comprehensive Electrocardiology, t. 1*. London: Springer London

Papik, K., Molnar, B., Schaefer, R., Dombovari, Z., Tulassay, Z., Feher, J., (1998). 'Application of Neural Networks in Medicine — a Review', n.d.

Rymarczyk, T., Kłosowski, G., Niderla, K., (2024). *Advantages of Convolutional Neural Network Compared to Multilayer Perceptron in Electrical Tomography.* Przeglad Elektrotechniczny, EBSCOhost'. Accessed

Rymarczyk, T., Kłosowski, G., Kozłowski, E., Tchórzewski, P. (2019). *Comparison of Selected Machine Learning Algorithms for Industrial Electrical Tomography*. Sensors 19, no. 7 (January 2019): 1521. https://doi.org/10.3390/s19071521

Shimazaki, A., Ueda, D., Choppin, A., Yamamoto, A., Honjo, T., Shimahara, Y., Miki, Y., (2022). 'Deep Learning-Based Algorithm for Lung Cancer Detection on Chest Radiographs Using the Segmentation Method'. Scientific Reports 12, no. 1 (14 January 2022): 727. https://doi.org/10.1038/s41598-021-04667-w

Wójcik, D., Rymarczyk, T., Oleszek, M., Maciura, Ł., Bednarczuk, P., (2021). 'Diagnosing Cardiovascular Diseases with Machine Learning on Body Surface Potential Mapping Data'. In Proceedings of the 19th ACM Conference on Embedded Networked Sensor

Systems, 379–81. SenSys '21. New York, NY, USA: Association for Computing Machinery. https://doi.org/10.1145/3485730.3492883

Wócik, D., Stefaniak, B., Woś, M., Kiczek, B., Rymarczyk, T., (2022). Image Reconstruction for Lung Monitoring in Wearable Electrical Impedance Tomography. | Przeglad Elektrotechniczny |EBSCOhost'. Accessed 27 April 2024. https://openurl.ebsco.com/EPDB%3Agcd%3A14%3A28641262/detailv2?sid=ebsco%3Aplink%3Ascholar&id=ebsco%3Agcd%3A155749160&crl=c

Vargas-Luna, F. M., Delgadillo-Cano,M. I., Riu-Costa, J. P., Kashina, S., Balleza-Ordaz J. M., (2024). 'Assessing Pulmonary Function Parameters Non-Invasively by Electrical Bioimpedance Tomography'. Journal of Medical and Biological Engineering 44, no. 1 (1 February 2024): 67–78. https://doi.org/10.1007/s40846-023-00842-8

Internet sources

Big Data Analytics in Healthcare — *A Systematic Literature Review and Roadmap for Practical Implementation*. Accessed 27 April 2024. https://ieee-jas.net/article/doi/10.1109/JAS.2020.1003384?pageType=en

PostgreSQL vs. MySQL vs. Commercial Databases: It's All About What You Need. (Accessed 27 April 2024). https://priv.gg/e/Postgresql%20Vs%20Mysql%20Vs%20Db2%20Vs%20Mssql%20Vs%20Oracle.pdf

ScienceDaily. 'Adaptive Optical Neural Network Connects Thousands of Artificial Neurons'. Accessed 27 April 2024. https://www.sciencedaily.com/releases/2023/10/231023124404.htm

Tissue Frequency Chart » IT'IS Foundation. Accessed 27 April 2024. https://itis.swiss/virtual-population/tissue-properties/database/tissue-frequency-chart/