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M.O. Lukianets, Y.S. Sulema

# REAL-TIME DATA VISUALIZATION FOR IOT NETWORK SYSTEMS: CHALLENGES AND STRATEGIES FOR PERFORMANCE OPTIMIZATION

*Abstract. Real time data visualization has become an essential tool for decision making systems in various industries, including finance, healthcare, IoT, and manufacturing. Real time data visu alization enables organizations to monitor and analyze data as it is generated, providing real time insights into critical business operations. However, real time data visualization poses sever al challenges, including performance, data quality, and visualization complexity. This paper will explore the importance of real time data visualization in IoT network systems, and the challeng es associated with it. Specifically, the paper will discuss the challenges of real time data visuali zation and ideas to increase performance. The paper will also provide a comprehensive analysis of the impact of real time data visualization on IoT network and decision making systems, high lighting its benefits and potential drawbacks. The paper will begin by discussing the importance of real time data visualization in IoT network systems, highlighting its role in providing timely insights into critical operations. It will then delve into the challenges associated with real time data visualization, including data quality, visualization complexity, and performance. The paper will provide a detailed analysis of each challenge, outlining the potential impact on real time data visualization systems and decision making processes. The paper will also explore ideas to increase performance in real time data visualization, including implementing high performance computing infrastructure, optimizing data processing and analysis, using caching techniques, using visualization techniques optimized for performance, implementing data compression, and using real time analytics. The paper will provide a comprehensive analysis of each idea, outlining its potential impact on real time data visualization systems' performance and overall effective ness. Finally, the paper will conclude by highlighting the importance of real time data visualiza tion in IoT network systems and the need to address the challenges associated with it. The paper will also provide recommendations about how to implement real time data visualization systems, outlining key considerations and best practices to ensure successful implementation and optimal performance.*
*Keywords: real time data visualization, IoT, decision making, performance optimization.*

**Problem Statement.** Data visualization has become an essential tool for IoT network systems. With the advent of real-time data, the ability to visualize this data in real-time has become increasingly important. Real-time data visualization pro-




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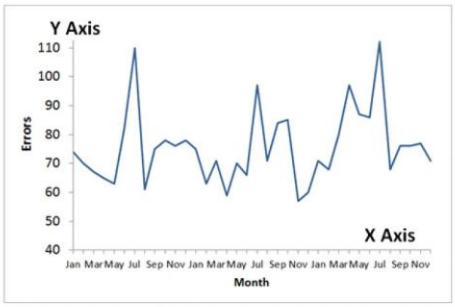
vides decision-makers with the ability to quickly analyze and interpret data as it is generated, allowing them to make timely and informed decisions. The amount of data generated by modern IoT network systems is constantly increasing, and it is becoming increasingly challenging to process and make sense of this data in a timely manner [1]. Real-time data visualization provides a solution to this problem by allowing decision-makers to identify trends and patterns quickly and easily in large datasets. Visual analytics "combines automated data analysis with interactive visualizations for aneffective understanding, reasoning, and decision making on the basis of very large and complex datasets" [2]. However, real-time data visualization also presents several challenges, including performance issues that can slow down the system and affect the accuracy of the visualizations.

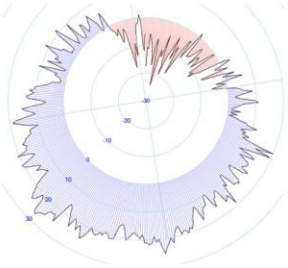
**Analysis of Recent Research and Publications.** Real-time data visualization is a process of generating and displaying data in real-time. It provides decision-makers with the ability to view data as it is generated, allowing them to make informed decisions based on current information. Real-time data visualization is particularly useful for IoT network systems that require timely responses, such as financial trading, transportation management, and emergency response systems. Real-time data visualization can be achieved using a variety of techniques, including dashboards, charts, graphs, and maps. Recent research in visual analytics specify different methods of visual representation and performance optimizations [3-8]. Various chart types are shown on Fig. 1.

Visualization techniques may be described in three dimensions: layout, scale, and representation. It is suitable for storytelling chart classification [5].

These visualizations are typically generated using data from real-time data sources, such as sensors, databases, and social media feeds. Real-time data visualization tools often provide users with the ability to filter and drill down into data sets, allowing them to quickly identify trends and patterns.

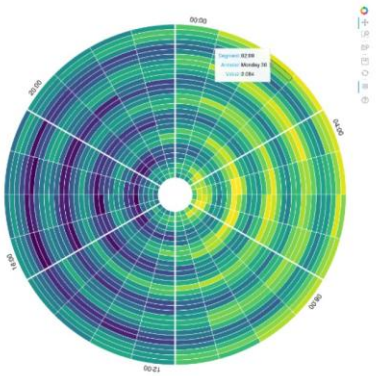



a) Line graph



b) Radial graph


c) Heatmap graph



d) Radial heatmap graph

Figure 1 - Time series visualisations in different techniques. Line graph (a), radial graph (b), heatmap graph (c), radial heatmap graph (d)

Real-time data visualization is particularly useful for IoT network systems that require collaborative decision-making. Collaborative decision-making involves multiple decision-makers working together. Real-time data visualization tools allow decision-makers to share data and collaborate in real-time, allowing them to make informed decisions more quickly and effectively. Electromagnetic situation awareness is an example of such decision making [8]. It utilises different visual analytics methods and charts, some of them are shown on Fig. 2.



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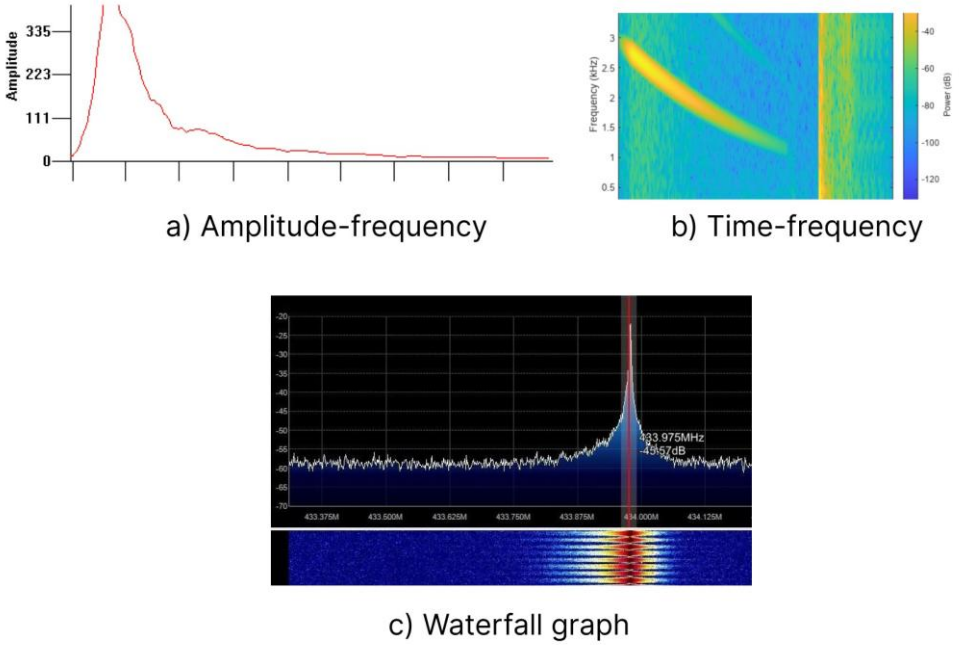


Figure 2 - Traditional spectrum diagrams: (a) spectrum amplitude-frequency diagram, (b) spectrum time-frequency diagram, (c) spectrum waterfall diagram

**Formulation of Research Objective.** The objective of this paper is to explore the challenges of real-time data visualization and propose strategies to optimize performance. Specifically, the paper aims to identify the performance issues that affect real-time data visualization and discuss potential solutions to these issues.

**Presentation of the Main Research Material.** A visualization system typically consists of several components including collection, data flow, processing, storage, and delivery. The collection component is responsible for gathering information while the data flow component facilitates the transfer of information from the collection components to the processing components. The processing components analyze the data and convert it into a suitable format for storage and delivery. Typically, the delivery is done through a visual interface such as a web or desktop program [9]. Let us formulate the challenges of real-time data visualization.

The field of visual analytics faces many challenges, especially when it comes to real-time data visualization. These challenges arise from specific applications of visual analytics, each with its own practical requirements in its problem domain. However, some challenges are common to more than one domain and application [1].

One of the most significant challenges is scalability. It is difficult to develop scalable visual analytics solutions that can handle both visual representations and automatic analysis. The solution needs to be able to scale in size, dimensionality,

data types, and levels of quality. Efficient methods are required to deal with noisy high-resolution input data as well as continuous input data streams of high bandwidth. Relevant data patterns and relationships need to be visualized on different levels of detail and with appropriate levels of data and visual abstraction.

Another major challenge is dealing with uncertainty. This is especially difficult in visual analytics due to the large amount of noise and missing values that originate from heterogeneous data sources and bias introduced by automatic analysis methods as well as human perception. To face this problem, the notion of data quality and the confidence of the analysis algorithm need to be appropriately represented. Analysts need to be aware of the uncertainty and be able to analyze quality properties at any stage of the data analysis process.

Hardware is also a significant challenge for real-time data visualization. More efficient computational methods and powerful hardware are needed to support near real-time data processing and visualization for large data streams. In addition to high-resolution desktop displays, advanced display devices such as large-scale power walls and small portable personal assistants need to be supported. Visual analytics systems should adapt to the characteristics of the available output devices, supporting the visual analytics workflow on all levels of operation.

Interaction is also a significant challenge in real-time data visualization. Novel interaction techniques are needed to fully support seamless intuitive visual communication with the system. The analyst should be able to fully focus on the task at hand and not be distracted by overly technical or complex user interfaces and interactions. User feedback should be taken as intelligently as possible, requiring as little user input as possible. Such interactions guarantee the full support of the user in navigating and analyzing the data, memorizing insights, and making informed decisions.

Evaluation is another challenge in visual analytics. Due to the interdisciplinary nature and complex visual analytics process, it is difficult to assess the quality of visual analytics solutions. A theoretically founded evaluation framework needs to be developed to assess the effectiveness, efficiency, and user acceptance of new visual analytics techniques, methods, and models. Such a framework will lead to a better understanding of the field and more successful and efficient development of innovative methods and techniques.

Finally, infrastructure is a challenge that needs to be addressed in real-time data visualization. Most current visual analytics solutions develop their infrastructures for solving their specific problems. Although some systems can be connected


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through various communication mechanisms such as direct library linking and web services, there is still a mismatch between the level of service provided and the real need for visual analytics in terms of fast and precise answers with progressive refinement, incremental re-computation, and steering the computation towards data regions that are of higher interest to the user. More research is needed to develop a high-level infrastructure to bind together all the processes, functions, and services supplied by various disciplines. There is also a need to build repositories of available visual analytics solutions to ensure that common components are reusable.

Real-time data visualization presents several challenges, including performance issues that can slow down the system and affect the accuracy of the visualizations. These issues can arise due to the large volume of data being processed, the complexity of the visualizations, and the limitations of the hardware being used.

To optimize performance, several strategies can be used to reduce the amount of data being processed. One such strategy is data aggregation, where data is summarized at a higher level to reduce the volume of data being processed. For example, instead of plotting every data point on a graph, the data can be aggregated into smaller time intervals or geographic regions, reducing the number of data points being plotted. This not only reduces the amount of data being processed but also makes the visualization easier to read. Such method as k-means and DBSCAN may be used for clustering. However, traditional clustering methods experience difficulties in achieving accurate and efficient signal clustering, so custom clusterization algorithms may be required for efficient work in certain applications [8].

Another strategy is data pre-processing, where the data is cleaned and transformed before being visualized. This can involve removing duplicates, filling in missing values, and transforming the data to a format that is more suitable for visualization. By pre-processing the data, the visualization can be made more accurate and meaningful.

Compression is another technique that can be used to reduce the amount of data being processed. Compression involves compressing the data into a smaller format, making it easier to store and process. This can involve using algorithms such as gzip or deflate to compress the data before visualization or clustering on IoT device side before sending.

In addition to reducing the amount of data being processed, several techniques can be used to improve the speed and accuracy of the visualizations. Caching is one such technique, where the results of previous visualizations are stored in memory for

future use. This can significantly improve the speed of the visualizations, as the data does not need to be reprocessed each time.

Indexing is another technique that can be used to improve the speed of visualizations. Indexing involves creating an index of the data, allowing the system to quickly access specific data points without having to scan the entire dataset. This can significantly improve the speed of visualizations, especially when dealing with large datasets. This method is suitable for visualizations that use both real-time and stored data, for example in signal classification applications.

Incoming data grouping is also an essential way of optimizing performance. Developing a new algorithm that can group many data chunks from numerous devices in a fast and memory-efficient manner may increase performance.

Finally, parallel processing can be used to improve the speed and accuracy of the visualizations. Parallel processing involves breaking down the data into smaller chunks and processing them simultaneously on multiple processors. This can significantly reduce the processing time, allowing the visualizations to be generated more quickly.

By implementing these strategies, decision-makers can make more informed decisions in real-time, improving the overall efficiency and effectiveness of the decision-making process. However, it is important to note that these strategies may not be suitable for all types of data and visualizations, and it is important to carefully evaluate each strategy before implementation. Additionally, it may be necessary to balance performance with accuracy, as overly aggressive optimization may lead to inaccurate or misleading visualizations.

**Conclusions.** Real-time data visualization faces several challenges that require further research and development to overcome. These challenges include scalability, uncertainty, hardware, interaction, evaluation, and infrastructure. Addressing these challenges will enable the development of effective and efficient real-time data visualization solutions that can provide valuable insights for IoT network systems.

Future research could focus on exploring novel visualization techniques that can effectively represent complex and large-scale data in a more intuitive and interpretable manner (e.g., for electromagnetic situatuion awareness). Additionally, advancements in data grouping and data pre-processing, such as clusterization and pre-drawing (visual elements grouping) may significantly optimize real-time data visualization algorithms that may improve perfomance.


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***Візуалізація даних у режимі реального часу для систем мереж IoT: виклики та стратегії оптимізації продуктивності***

*Візуалізація даних в реальному часі стала невід'ємним інструментом для систем прийняття рішень у різних галузях, включаючи фінанси, охорону здоров'я, IoT та виробництво. Візуалізація даних в реальному часі дозволяє організаціям відслідковувати та аналізувати дані в момент їхнього створення. Проте візуалізація даних в реальному часі має перед собою кілька викликів, включаючи продуктивність, якість даних та складність візуалізації. У цій статті було розглянуто важливість візуалізації даних в реальному часі в системах IoT та пов'язані з цим виклики. Зокрема, у статті обговорено виклики візуалізації даних в реальному часі та ідеї щодо підвищення продуктивності. Стаття також надає комплексний аналіз впливу візуалізації даних в реальному часі на системи IoT та процеси прийняття рішень, висвітливши її переваги та потенційні недоліки. Стаття містить обговорення важливості візуалізації даних в реальному часі в системах IoT. Далі у статті проведено аналіз викликів, пов'язаних з візуалізацією даних в реальному часі, включаючи якість даних, складність візуалізації та продуктивність.*


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*Стаття представляє детальний аналіз кожної проблеми, висвітлюючи потенційний вплив на системи візуалізації даних в реальному часі та процеси прийняття рішень. Крім того, у статті висвітлені ідеї щодо підвищення продуктивності візуалізації даних в реальному часі, включаючи впровадження високопродуктивної обчислювальної інфраструктури, оптимізацію обробки та аналізу даних, використання технік кешування, використання технік візуалізації, оптимізованих для продуктивності, впровадження стиснення даних. У висновку у статті підкреслено важливість візуалізації даних в реальному часі в системах Інтернету речей та необхідність вирішення пов'язаних із цим викликів. Стаття також надає рекомендації щодо впровадження систем візуалізації даних в реальному часі, висвітлюючи ключові питання та найкращі практики для забезпечення успішного впровадження та оптимальної продуктивності.*

*Ключові слова: візуалізація даних в реальному часі, IoT, прийняття рішень, оптимізація продуктивності.*

**Лук'янець Михайло Олександрович** – *аспірант кафедри програмного забезпечення комп'ютерних систем, Національний технічний університет України «Київський політехнічний інститут імені Ігоря Сікорського».*
**Сулема Євгенія Станіславівна** – *д.т.н., доцент, завідувач кафедри програмного забезпечення комп'ютерних систем, Національний технічний університет України «Київський політехнічний інститут імені Ігоря Сікорського».*

**Lukianets Mykhailo Oleksandrovych** - Postgraduate student of the Computer Systems Software Department, National Technical University of Ukraine "Igor Sikorsky Kyiv Polytechnic Institute".
**Sulema Yevgeniya Stanislavivna** – Doctor of Technical Sciences, Associate Professor, Head of the Computer Systems Software Department, National Technical University of Ukraine "Igor Sikorsky Kyiv Polytechnic Institute".