Big Data, Internet of Things, Augmented Reality: technology convergence in visualization issues

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Abstract. The paper reviews the current situation of the Augmented Reality and Internet of Things markets. The implementing possibilities of AR for Big Data visualization from IoT devices are considered in this paper. The review and the analysis of methods, tools, products and data system of the visualization are presented. The paper provides an overview of the programs and devices of Augmented Reality, and an overview of development environments. The paper presents the existing classifications of computerized data visualization tools and proposes new classification, which takes into account interactive visualization, the purpose of the tool, the type of software product, the availability of ready-made templates, and other characteristics. The work results can be used for further research in the fields of the Internet of Things and visualization of Big Data through Augmented Reality.

1. Introduction

The introduction of new technologies is often focused on simplifying the routine actions of a person in everyday life. An example is the introduction of the Internet of Things technology, which requires an integrated approach to development that combines new technologies, skills and capabilities supported by effective management and organization. Such technology requires the support of user interaction and the digital ecosystem to enable the management of connected equipment. For this, it is necessary that the program can analyze and visualize the data obtained from the sensors. The relevance of this work lies in the fact that the two-dimensional visualization of data obtained from the sensors of the Internet of things, is not enough.

In this regard, there is a big growth in services for analyzing and visualizing the data received from the sensors. The novelty of the work lies in the fact that for the most part, such services represent information in a two-dimensional form. The problem is that programs of this format cannot ensure the full assimilation of information. With a large amount of data, the user may miss key points and, for example, in production, do not notice breakages due to clutter of the interface.

Fortunately, nowadays modern technologies allow solving this problem with the help of augmented reality [1]. Consideration of the use of this technology in the field of IoT, it is possible to present its use in enterprises for timely identification of problems, in the home for remote control of equipment, in large production facilities for personnel training through the visualization of processes and instructions. In this regard, the purpose of this work is to identify methods, approaches and technologies for visualizing big data on the Internet of things using augmented reality.

2. Big Data

Over the past two decades, technological advances have led to a huge increase in data volumes. The term Big Data (Big Data) was coined for working with such data streams. This type of data is not only characterized by a large volume, but also demonstrates other unique characteristics compared to traditional data. For example, big data is usually unstructured and may require real-time analysis. That is why for working with big data many new systems were created for collecting, transmitting, storing and processing large-scale data.

Due to the great popularity and diversity of Big Data technology, today there is no generally accepted definition for this term. In essence, big data means not only a large amount of data, but other functions that distinguish it from the concepts of “massive data” and “very large data”. In the literature, you can find many definitions for big data, consider three of them, which well explain the essence of the term big data.

One of the currently popular definitions appeared back in 2001, in the report of META Group analyst (now Gartner) Dag Lani [2], who noted the equivalence of data management issues in three aspects (3Vs):

- Volume. Big data is very large, often in petabytes or more. Examples include user data on Facebook, the flow of people on the subway or transactions using credit cards;
- Velocity. Big data is often generated continuously, often even in real time. For example, Twitter messages, cell phone locations, weather and air quality sensors;
- Variety. Big data can be of any type consisting of numbers, text, photos, video, audio and other data. Therefore, Big Data analysis must be flexible enough to deal with any type of data and be able to combine them.

Big data has three varieties: structured, semi-structured, and unstructured. Traditional data is usually structured and therefore easy to use and can be easily stored. However, the vast majority of today's data from sources such as Facebook, Twitter, YouTube and other user-generated content is unstructured. The high rate of receipt of large data means that data sets should be analyzed at a rate corresponding to the speed of data production.

Today, big data can be found in many areas. One of the most common ways to get big data is to collect data from sensors and devices. The popular branch of the development of this technology is the Internet of Things (IoT). It implies a global collection of all indicators from several sensors simultaneously (often in real time), the compilation of these data and their analysis.

3. Internet of Things

The Internet of Things (IoT) provides a network for connecting people, things, programs and data over the Internet to provide remote control and interactive implementation of services. Today, the amount of mobile devices with Internet connection exceeds the number of people on Earth. Moreover, in 2015, Gartner predicted [3] that by 2020 about 20.8 billion smart devices will be connected to the IoT. In order to support the work of devices connected to the IoT, it is necessary to have a special Internet of Things support service. Such IoT services need to collect, analyze and process information about sensors, they must have an interface for the operational management of information. The data collected from IoT devices can be impressive in size, since the number of sensors on the Internet of Things is very large. Therefore, a platform that can collect and store a huge amount of information from sensors is needed to control IoT. Such a platform should include IoT databases where cloud computing support is needed. Moreover, IoT data analysis and Big Data support is required.

The economic effect can be seen where the connection between the machines (hereinafter - M2M) is becoming increasingly important. However, person-to-person (hereinafter - P2P), person-to-machine (hereinafter - P2M) and machine to person (hereinafter - M2P) connections still remain the majority of the economic value of IoT. In the table below you can see the comparison of M2M with M2P or P2M, as well as with P2P technology.

IoT is used in various fields, consider some of them:

- Security. In this area, IoT is used to monitor alarms, monitor and control surveillance systems in real time and track people;

- Transport sphere. Intelligent applications for transportation systems are used for fleet management, road safety, emissions control, toll payments, real-time traffic monitoring, etc;
- Health. In this area, IoT is used for e-health, which includes individual health systems based on sensors for the human body;
- Utility management. The Internet of Things allows you to measure, prepare, and bill for gas, water, electricity, and more;
- Production. Production control is carried out through the monitoring and automation of the product chain;
- The scope of services. Control of supply and distribution, vending machines can also be monitored, and support can be provided in managing and providing services;
- Management of funds. Campus, building and home automation can be reached using IoT technology.

4. Augmented Reality

Augmented Reality (AR) is a technology that allows a user to real-time overlay virtual text or computer-generated images onto objects in the real world. Recognition occurs, usually with the help of a camera, and the output of augmented reality through the user's screen, telephone, monitor, helmet or Augmented Reality glasses, window or windshield of the car. Virtual text or image can be superimposed on the selected objects in the environment surrounding the user, to display additional information about the selected object.

It is customary to use two basic definitions of augmented reality. In 1994, Paul Milgram described the continuum “virtuality-reality” [4], i.e. the space between reality and virtuality, between which are Augmented Reality and augmented virtuality (figure 1). The real environment and the virtual environment unite in a mixed reality, where, in turn, augmented reality is based more on reality, and augmented virtuality on virtuality. Thus, Augmented Reality is the result of adding virtual objects to the number of objects perceived by man as elements of the real world.

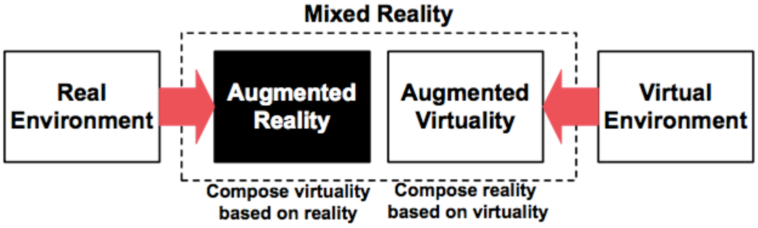

Figure 1. Milgram definition.

Augmented reality is based on context-sensitive computations. Thanks to this technology for the user, the real world and virtual objects coexist on the same view. For example, this technology can be applied to museums. If you point the camera of a smartphone with a special application of augmented reality on any exhibit, information about it will be displayed next to the exhibit. The user of augmented reality can receive useful information about a location or objects and can interact with virtual content in the real world.

5. Data visuialization methods

5.1. Classification

There are many computer visualization tools that allow you to convert large amounts of abstract data into formats that are effective for perception, cognition and communication. For example, in the work [5] the following classification of computer visualization tools is given:

1) Tool functionality: user (professional or beginner), teamwork support (how many people can simultaneously develop a model), extensibility (possibility of making changes), scalability.
2) Methods (characteristics of the methods used): number of methods, method type.
3) Task (characteristics of the problem to be solved): type of information (quantitative, qualitative), subject area (science, business, education)

4) Manufacturer (characteristics of the product): manufacturing-firm: (domestic, foreign), type of product (commercial, training and demonstration, conditionally free)

This classification considers the functionality of the tool from the point of view of user experience: the level of user skills, support for teamwork, extensibility and scalability. The availability of ready-made templates, interactive visualization and other important characteristics are not taken into account in this work. The division of instrument manufacturers into domestic and foreign ones can be replaced by the multi-lingual nature of the proposed interfaces.

Consider the following classification of visualization and data analysis tools [6], the following classification of visualization and data analysis tools is proposed:

1) Category: analysis and charting, PC application, geographic information systems (GIS), library, network analysis, statistical analysis, time data analysis, data retrieval, data cleansing, data conversion, application/service for visualization and analysis, word clouds.
2) Multiple user support: true or false.
3) Data display on the map: true or false.
4) Platform.
5) User skill level: users who can work with spreadsheets, partially advanced users who are not afraid to spend two hours learning a new application, advanced users, users with programming experience or specialized knowledge in the field of GIS or network analysis.
6) Storage and processing location: user device, external server, public external server.
7) Posting results to the web: yes, with plugin, as a picture, no.

The considered classification summarizes such phenomena as a PC application, library, network analysis, statistical analysis and a word cloud. However, a PC application and a library are types of software, network analysis and statistical analysis are the purpose of the tool, and the word cloud is a data visualization method.

We have developed a new improved classification of computer visualization tools that expands and improves the previously proposed options:

1) Purpose: general purpose; specialized (GIS, business intelligence tools, network analysis); auxiliary (designed to prepare data for visualization).
2) User skill level: beginer; intermediate; advanced; user with programming experience or special knowledge.
3) Software: programming language (R, Python); library (D3, ChartJS, Highcharts JS, Raphaël и др.); application/service.
4) Platform.
5) Distribution: commercial; conditionally free; free.
6) Multilingual interface: yes; no.
7) Need to register: yes; no.
8) Multiplayer mode: yes; no.
9) Types of visualized data: qualitative; qualitative and quantitative; quantitative.
10) Supported Databases and file formats.
11) Availability of ready-made templates: yes; no.
12) Interactive visualization: yes; no.
13) Storage and processing location: user device; external server; public external server.
14) Formats of export results.

This classification takes into account interactive visualization, the purpose of the tool, the type of software product, the availability of ready-made templates, and other characteristics.

4.2. Analysis of Big Data visualization methods

The aggregated data from all devices connected to the IoT network must be correctly reproduced for the decision maker. For these purposes, visualization is a suitable tool. Data visualization represents data in some systematic form, including attributes and variables for a unit of information. Visualization approaches are used to create tables, charts, images, and other intuitive ways to display data. Big data visualization is not as simple as traditional small data sets [7]. The expansion of traditional approaches to visualization has already appeared, but far from enough. With large-scale data visualization, many researchers use feature extraction and geometric modeling to significantly reduce the size of the data before actually rendering the data. Choosing the right data representation is also very important when visualizing big data [8].

Often, standard methods of data visualization are used, which include such methods as a table, histogram, scatter plot, line diagram, pie chart, block diagram, bubble chart, combination of charts, time line, entity relationship diagram, etc. In addition, the standard methods of data visualization include additional methods: parallel coordinates, treemap, cone-shaped tree, semantic network, etc [7].

Parallel coordinates (figure 1) are used to construct individual data elements in many dimensions. This method of data visualization is very useful when displaying multidimensional data [9].

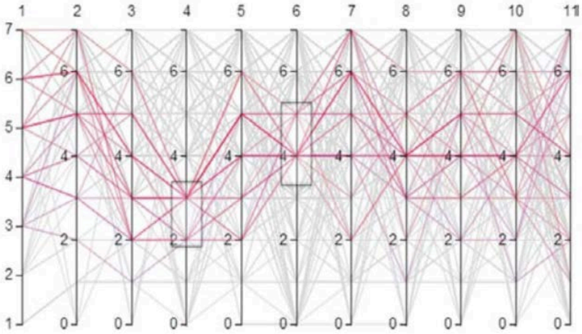

Figure 2. Parallel coordinates.

Treemap (figure 2) - an effective method of visualizing the hierarchy, which is a map, divided into sections. The smallest rectangles represent one measure, while color is often used to represent another measure of data. Figure 2 shows an example of a treemap collection set for streaming music and video tracks in a social networking community [10].

A cone-shaped tree is another method that displays hierarchical data, such as an organizational body in three dimensions. Branches grow in the form of a cone. The semantic network is a graphical representation of the logical connection between different concepts. It generates a directed graph, a combination of nodes or vertices, edges or arcs, and an inscription above each edge [7].

Visualization is not only static, but also interactive, thanks to such approaches as scaling (zooming in and out); review and detail; pan; as well as focus and context or fisheye [7]. Below are the steps for interactive visualization:

- Choice. This implies an interactive selection of data objects, a subset, parts of whole data, or the entire data set in accordance with the interests of the user;
- Linking: useful for linking information between several types of graphs. An example is shown in figure 3;
- Filtering: helps users adjust the amount of information to display. It reduces the amount of data and focuses on information of interest;
- Regrouping or reuse: since spatial layout is the most important visual display, rebuilding the spatial layout of information is very effective for creating different ideas.

The scalability and dynamics inherent in big data are the main problems in visual analytics. Big data visualization with diversity and heterogeneity (structured, semi-structured, and unstructured) is a big problem. As described above, speed (Velocity) is one of the important factors for analyzing Big Data. Cloud computing and an advanced graphical user interface can be combined with big data to better manage the scalability of big data [11].

Big data often has an unstructured data format, so due to bandwidth limitations and power requirements, the visualization must fit the data in order to efficiently get up-to-date information. Because of the large size of the data, there is a need for parallel computations, the task of which is to distribute computations for independent tasks that can be performed simultaneously [12].

The following problems exist in Big Data visualization [13]:

- Visual noise. Most of the objects in the dataset are too relative to each other. Users cannot separate them as separate objects on the screen;

- Loss of information. To simplify the calculations, it is often necessary to reduce the data sets, which leads to loss of information;
- Complicated image perception. Data visualization methods are limited not only by the aspect ratio and resolution of the device from which the visualization is viewed, but also by the physical limitations of perception;
- High speed image change. Users observe the data and cannot respond to the amount of data changes or their intensity on the display;
- High performance requirements.

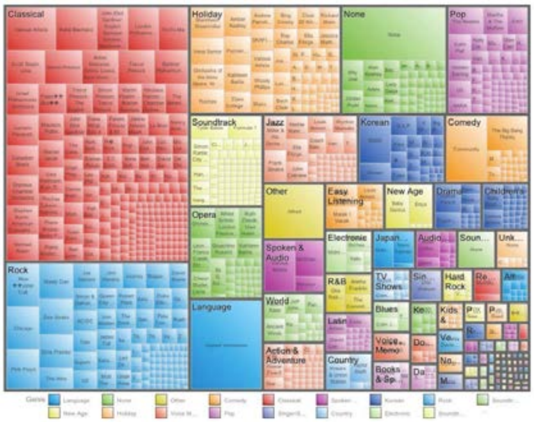

Figure 2. Analysis of musical compositions using a treemap.

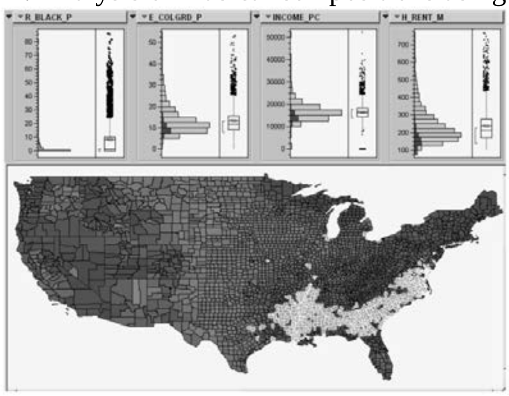

Figure 3. Interactive linking between histogram graphs and a geographic map.

Visualizing each data point can overwhelm the schedule and can suppress users' perceptions and cognitive abilities, and reducing data by sampling or filtering can lead to a loss of interesting emissions and deviations. Requesting large data warehouses can lead to high latency, disrupting real-time interaction [14].

Ways of solving problems of Big Data visualization [15]:

1. Satisfying the need for speed. This implies improved hardware with increased memory and powerful parallel processing,
2. Understanding the data. One solution is for people who receive data to have relevant experience and knowledge for quick understanding,
3. Solving the problem of data quality. It is necessary to control that the data arriving at the visualization were cleared from unnecessary information,
4. Synthesis of information. One way is to combine the data into a higher-level view, where smaller groups of data are visible and the data can be effectively visualized,
5. Create exceptions for emissions. A possible solution is to remove outliers from the data or create a separate chart for outliers.

Big data can be visualized using a number of approaches and methods that were analyzed and classified (table 1) according to the following data criteria: large data support, support for different types of data, and the capacity to dynamically display data changes [4].

- Treemap: based on the visualization of spatial images of hierarchical data;
- Circle Packing: A direct alternative to treemap. However, it uses circles as a primitive form, which can also be included in circles from a higher level of hierarchy;
- Sunburst: uses a treemap visualization and converts it into a polar coordinate system. The main difference is that the variable parameters are not the width and height, but the radius and length of the arc;
- Parallel coordinates: extends visual analysis using a variety of data factors for different objects;
- Streamgraph: this is a type of graph of a stack region that is offset around a central axis, which results in a smooth and organic form;
- Circular Network Diagram: The data object is placed around the circle and connected by curves based on the level of their interconnections. Different line widths or color saturation are commonly used to measure the coherence of an object.

Table 1. Analysis of big data visualization methods.

	Large amount of data	Variety of data	Data dynamics
Treemap	+	-	-
Circle Packing	+	-	-
Sunburst	+	-	+
Parallel coordinates	+	+	+
Streamgraph	+	-	+
Circular Network Diagram	+	+	-

Many data visualization tools work on the Hadoop platform. Such modules in Hadoop are: Hadoop Common, Hadoop Distributed File System (HDFS), Hadoop YARN, and Hadoop MapReduce. There are also separate softwares, but they all represent a two-dimensional visualization of data, which is a difficulty for the user to understand the information. The solution to this problem is to use augmented reality as a visualization tool, which will facilitate the work of the user and allow you to visualize the data in a convenient form.

6. Big Data, IoT and AR: technology convergence in visualization issues

In 1979, a major accident at a nuclear power plant occurred in the United States, the cause of the accident was erroneous actions by personnel who did not understand the incoming data and did not identify the problem in time [9]. The introduction of Augmented Reality in the visualization of data collected from IoT-sensors, will make work in many areas more secure and effective. The use of this technology will allow real-time monitoring of the indicators of the sensors, output the data in a visual form, it is also possible remote user interaction with the equipment. Thus, not only the working personnel who are in close proximity to the equipment can make an inspection, but also the manager will be able to more accurately control the production situation with the help of installed smart sensors in all rooms. If something goes wrong, workers can instantly fix the problem, or transmit the data to engineers outside the building.

Also, this technology can be used for training and staff training. Companies can develop interactive manuals in augmented reality, filling them with interactive 3D equipment models and visual step-by-step instructions. For example, global manufacturer Caterpillar Inc. makes good use of AR to train its engineers and makes them more efficient. Engineers can use AR glasses or a smartphone to get virtual, step-by-step live instructions on how to efficiently perform machine repairs and other maintenance tasks. Many examples can also be seen in the areas of health, education, aviation and space, travel, real estate and other sectors.

The interaction of AR and IoT requires a large number of calculations, in addition, the volume of processing of augmented reality directly affects the power consumption of the device and its lifespan. That is why to work with AR on smartphones an additional cloud database is needed to reduce the load, save energy and overcome the limitations of the phone's memory. It is worth noting that the use of cloud technologies should be controlled by adaptive management, since the transfer of all computational processes to the cloud platform can lead to large delays in the operation of the program. To use cloud resources efficiently, you need to monitor the cloud server load and network congestion status so that they are balanced. It is necessary to monitor the state of the network, the status of the cloud server, the energy status of the device and the quality of perception (QoE, Quality of Experiance).

Using an AR application on smartphones, tablets, or corporate AR headsets, workers can monitor connected equipment to identify problems and perform maintenance. AR headsets, such as Google Glass Enterprise and Microsoft HoloLens, can also be useful in enterprises, displaying step-by-step online training and tutorials for assembling and operating equipment that would otherwise require reading thick technical manuals and instructions.

To create an Augmented Reality program with the ability to visualize data from the IoT sensors, you can use the existing augmented reality SDKs: ARToolkit [16], EasyAR [17], OpenCV [18], Maxst [19], Kudan [20], Catchoom On-Device Image Recognition SDK [21] and Vuforia SDK [22]. With the help of such SDKs, only a part with augmented reality can be developed, but additional programs will be needed to connect IoT devices and collect data.

For the productive implementation of programs, there are ready-made solutions that combine all stages of program development, including connecting sensors and visualizing data. The main leaders among the platforms for creating programs with AR for the Internet of Things are PTC, Augmenta, Bosh, Reflect.

Currently, the main area of convergence of the listed technologies is the visualization of big data coming from IoT-devices in real time on mobile devices with augmented reality function. Conventionally, we can distinguish the following types of convergence:

1. Visualization of sensor data and object management.
2. Monitoring equipment performance and decision support systems. The information presented in a visual form will allow timely troubleshooting equipment problems and improving the quality of manufactured products. Ideally, this technology should be implemented at every stage of production.
3. People will be able to interact with electronics using 3D interfaces, which raises new questions about the energy efficiency of mobile devices, which are displays for data visualization (smartphones, tablets, smart watches or AR helmets).

The current trends in the field of the Internet of Things are the creation of new hardware platforms, the development of specialized operating systems, the development and optimization of application layer protocols, and the development of models and methods for data visualization aimed at improving the energy efficiency of the Internet of Things, including mobile devices, to increase battery life. The lack of mathematical models, methods and tools for organizing dynamic reconfiguration of graphical interfaces of IoT devices (including using the AR) is a serious obstacle for further research, as well as for increasing the time for effective functioning of mobile devices and networks of software systems with limited resources. In this regard, the task of research and development of an integrated model that makes it possible to assess the efficiency of energy consumption and other limited resources of mobile devices, methods that make it possible to optimize the consumption of resources of a mobile device according to the criterion of maximizing residual energy taking into account the limitations and requirements of users for final applications and graphic interfaces, and means of organizing reconfiguration of graphic interfaces of devices.

7. Conclusion

The connenction of AR with the IoT ecosystem presents tremendous opportunities for various industries. Using this approach can make machines smarter by integrating sensors and intelligent systems that can monitor and produce data to solve problems in a timely manner and prevent downtime and breakdowns. IoT platforms provide a scalable, flexible, and secure way to cost-effectively extend AR applications. The use of such programs will allow companies to remotely diagnose and fix problems, preventing equipment and system system failures before they occur. This predictive service not only eliminates system downtime, but also optimizes energy use, which saves money. This paper proposes a classification of computer-based data visualization tools that can be used in developing a decision support system in the data visualization field.

In an attempt to frame the future of the research field, we identify a number of tasks that need to be addressed in the nearest future on the interdisciplinary basis:

1. Harmonization of terminology and lexical correspondences in order to improve professional and scientific communication.
2. Development of projects classification that can be implemented in the field of Big Data visualization with Augmented Reality.
3. Analysis of psychological and social impact of such projects, processing of feedback.
4. Development of a mathematical model of the process of reconfiguring the AR user interface to visualize data from real-time IoT devices, in terms of preserving the quality of service of the user interface.
5. Development of a method for dynamic design (reconfiguration) of the user interface AR on mobile devices with limited resources, while maintaining the quality of the user interface service.
6. Quantitative and qualitative evaluation of the developed models and methods.

In addition, it should be noted that for a better work with IoT and visualization using augmented reality of the collected data, DNS solutions of a new generation with intelligent routing are needed so that augmented reality programs interact with the cloud through the highest throughput, optimizing performance and ensuring uninterrupted user work.

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