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Subject review
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Design of Information Visualizations in the Internet of Nano-Things Air Quality Systems

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Abstract: Today's age is characterized by large amount of information that surrounds us in which visual information plays a significant role. Nanosensor air quality measurement systems that use Internet of Nano-Things technology enable the collection of big data. Ease of display and storage of information that the user can easily interpret are imperative in designing a visual interface. Only a good combination of visual elements complemented by data and map display will contribute to the clarity of the processed data. This paper will give an overview of the factors that affect the excellence of the transmission of visual information. Ways of presenting visualizations of air quality data measured by IoNT systems will be discussed through descriptive and empirical analysis of visualizations. A special emphasis is on the review of existing practices and principles, and the possibilities of visual presentation of information in this area will be explained through the discussion.

Keywords: air quality; design; information visualization; IoNT; nanosensors

1 INTRODUCTION

Air pollution rose sharply after the first industrial revolution [1]. Development of new production processes, increased transport of people and goods, and use of energy are the factors that contributed to the rise of this problem [2]. This rough division in a way also speaks about the pollutants that are dominant in the air during these processes. Everything mentioned above led to the need for quantitative and qualitative measurements of air pollutants. As the need for these measurements grew, measurement methods evolved, and new technologies emerged, and are still emerging.

One of the significant technologies in this field is the technology that uses the Internet of Nano-Things (IoNT) system. The mentioned technology uses nanomaterials, which in relation to the traditional ones (materials whose particles are greater than 100 nanometers) have the characteristics of desirable required properties that their size brings them. Materials of molecular or atomic sizes from 1 to 100 nanometers are used which is the main feature of nanotechnology [3-6]. In addition to their specific size after which they got their name, they owe their properties also to their shape and composition [7, 5].

Examples of the special properties of nanomaterials can be observed in nature and phenomena from our environment. Thus, some examples of nanotechnology in nature are the lotus flower that "repels" water, is always clean, and cannot get wet (the so-called lotus effect), a lizard that climbs on a smooth surface, and butterfly wings that change color [5]. Preferred properties for materials used in IoNT are characterized by increased selectivity and sensitivity in the detection of air pollutants. Nano-devices used in the IoNT system are in charge of performing all functional tasks [8].

The idea of IoNT was presented by Ian F. Akyildiz and Josep M. Jornet in the paper *The Internet of Nano-Things* as a combination of a network of physical objects that exchange data through nano-communication [3]. The components of the IoNT network change depending on the context [9]. Nevertheless, we can define elements that are always needed and used frequently. Thus, Akyildiz and Jornet [3] presented the components and architecture of an IoNT system consisting of nano-nodes, nano-routers, nano-links, nano-micro interfaces, gateways, and micro-links.

The most important parts are nano-nodes, nano-routers, nano-micro interfaces, and gateways. Nano-nodes are sensors and at the same time the smallest and simplest nano-devices that perform certain tasks [6]. Nano-routers control the nodes by aggregating the data obtained from them and can control the behavior of the nodes via simple commands (on and off, read values, etc.) [10]. Nano-micro interfaces enable the reception and transmission of information coming from nano-routers and perform a hybrid function by communicating using nano-communication and conventional network communication, while gateways are responsible for controlling the system remotely [11].

The ideal sensor would have features of high sensitivity, dynamic range, selectivity and stability, low detection limit, good linearity, fast response, and long life cycle [12]. The most common classifications of nanosensors are according to the conversion mechanism, recognition principle, and application [13]. According to the conversion mechanism, they are divided into electrical, optical, thermal, piezoelectric, etc., according to the principle of recognition into enzymatic, biological, molecular, etc., and according to the application to environmental, food, medical, etc. [14].

A well-designed graphical interface allows the viewer ease of perception and using and storing large amounts of data collected using nanosensors. The aim of this paper is to present information visualization methods obtained in the field of air quality control and to raise awareness of the importance of the role of information visualization in quality transmission of information. To review the role of visualizations within the IoNT system that measures air quality, a systematic study of the relevant literature and existing solutions was conducted. The keywords used were: nanotechnology, nanosensors, communication, IoT, IoNT, information visualization, data visualization, visual perception, air pollution, and air quality. In the second part of the research, we conducted a two-part research consisting of a descriptive and empirical analysis.

2 APPLICATION OF NANOSENSORS IN AIR QUALITY MEASUREMENT

Air quality refers to the measurement of the state of the air in relation to human needs and is related to health. Pollution is used to describe substances that lower the air quality [15]. Nanosensors are used to monitor and identify air pollution in high concentrations for the purpose of monitoring toxins, heavy metals, and organic pollutants in air, water, and soil [13, 16, 9]. The most common air pollutants that are measured are ozone, sulfur dioxide, carbon monoxide, nitrogen dioxide, ammonia, and volatile organic compounds (VOCs) [12].

Detection of air pollution requires the simultaneous detection of oxidizing and reducing gases in the presence of many potentially interfering molecules under stable conditions [17]. Nanonetwork enables air quality control and management [10]. The current problems of air quality sensors are the lack of sensitivity, accuracy, and stability, and the reduction of these problems lies in nanomaterials [14]. In many cases, nanosensors have proven to be an effective alternative to conventional pollution detection techniques, so metals and metal oxides can be used as electrochemical sensors due to their oxidizing form to detect toxins from the environment [12, 13]. For the detection of nitrogen dioxide, a nanostructured sensor based on a metal oxide semiconductor is mentioned in the literature, and a nanostructure-based tin oxide sensor with excellent selectivity, stability, and fast response time is good for the detection of formaldehyde [12].

Many sensors are needed to cover one city and although the costs are low, the implementation potential is demanding [16]. Due to the rapid development of this area, all these items are evolving and improving every day.

3 INFORMATION VISUALIZATIONS USED IN THE IoNT SYSTEM

The human visual system is based on a complex information processing system designed to optimally extract environmental information [18]. Interpretation of visual information with the use of an optimal combination of visual-artistic, empirical-statistical, and mathematical skills enables easier interpretation of the measured data [19]. Using and combining the mentioned skills, the designer creates an abstract visualization of the data that gives the user the ability to detect patterns, groups, gaps, and deviations within the statistical data [20].

William Playfair is considered the founder of graphical methods of statistics because he developed or improved almost all basic types of visualizations [19]. The basic types of visualization are graphs, maps, network diagrams, and composites [21]. Graphs are the most used type of visualization in data analysis, and some of the most used graphs are line graphs, bar graphs, scatter plots, heat maps, etc. [21]. On the graph, the data are coded with symbols that have a different shape, length, width, height, position, slope, area, angle, color, and shade [22, 23]. A typical graphical representation of information provides two spatial and three dimensions of color [24]. One of the ways of displaying information is through interaction which allows a quick search of the information network, but if the information can be perceived without interaction, then the cognition process will be the fastest [25]. Woods defined cognitive tools that support control and focus attention through accessibility, partial information, and mental economics. Through accessibility, the user perceives information without losing attention, through partial information he decides whether to redirect his attention, and through mental economy he processes information without cognitive effort [26].

Some visualizations have turned into Norman's [27] everyday things, have already existed for centuries, and their functioning has been explained to us in elementary school (line graphs, pie charts, etc.) [28]. Some of the prominent authors within the field of information visualization such as Alberto Cairo, Cole Nussbaumer Knaflic, Ben Shneiderman, Edward Tufte, and Colin Ware, have presented their principles for information visualization which are used today. Thus Cairo [22] emphasizes five qualities of excellent visualizations: truthfulness, functionality, aesthetics, insight, and enlightenment. Nussbaumer Knaflic [29] singles out six key steps in visualizing information: understanding the context, choosing an appropriate visual representation, removing clutter, focusing on specific places, thinking like a designer, and telling a story. Shneiderman [20] presents the Shneiderman mantra of overview first, zoom and filter, then details on demand, while Tufte [19] presents his data-ink ratio, which represents the proportion of ink graphics dedicated to the non-redundant display of data.

Ware [21] divided the visualization process into seven basic steps: description of high-level cognitive tasks, data inventory, analysis of cognitive task requirements, identification of visualization types, recognition and selection of cognitively effective interaction methods, prototyping and application, and evaluation. Through visualizations, we display data, lead the observer to think about the substance, avoid data deformation, display a large amount of data in one place, encourage the human eye to compare different types of information, and discover data through different levels [19]. Only by applying all the above-mentioned parameters can we design a visualization that will be useful and understandable to the observer.

4 EXAMINING AIR QUALITY INFORMATION VISUALIZATIONS IN THE IoNT SYSTEM

Nanosensors collect, accumulate, and transmit data over the Internet to the graphical interface. The interface is a medium through which the user can interpret the collected data and it is therefore important that the data is visualized accurately, and that the user can extract certain insights from them. Users that use air quality interfaces are the commercial users (the public) who are interested in receiving information about the air quality in their environment, but also experts who analyse this information. Our research was conducted in two stages. In the first stage we used a descriptive analysis to analyse existing portals which use air quality data visualizations. In the second stage we conducted an empirical research in which we examined the visual perception and attitudes of the respondents related to the visualization of air quality data. Data were collected in year 2022 on a sample of 59 respondents, of which 35 (59%) were female, and 24 (41%) male. The age group was diverse, with 17 (28%) of respondents being from age 18 to 25, 18 (31%) from 26 to 35, 18 (31%) from 36 to 55, and 6 (10%) above 56 years old. We used a survey for the data collection process, and a questionnaire consisting of 14 questions (single selection, multiple selection, Likert scale) for the instrument. The goal was to examine the respondents' visual perception of air quality data visualizations. We wanted to examine and define to which extent the participants use these kinds of information and in which way they perceive them. Given all the above, we set two hypotheses:

H1: There is no difference in the degree of agreement with the display of clarity and understandability between visualization.

H2: The colors used in all visualizations are understandable to respondents.

4.1 Descriptive analysis

In the first stage of the research, we analysed six different platforms that use air quality data visualizations. The human visual system is cognitively more effective if there is a particular external artifact such as a map, shown in Fig. 1, rather than just a mental image of certain data [30]. The visual elements shown in Fig. 1 and Fig. 2 show that a combination of a map and different visual elements can provide good pollution measurement information regardless of the size of the area for which the data is displayed, or whether it is a local or global representation of pollution. The differences between the two views are found in the selected visual elements. In the local view, color and geometric shapes were used, while in the global view, only color was used. It is very likely that on the global display the geometric figures would not be legible and would not contribute to the ease of information transfer, which is not the case with local displays.

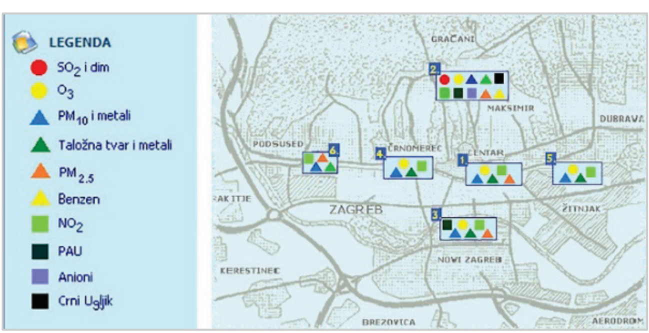


Figure 1 Example of pollution on a map, overview of locations and types of pollutants on permanent measuring stations in Zagreb [31]

Statisticians need to know the structure of certain data before they start applying analytical procedures and techniques, and the graph has proven to be the best tool for exploratory data analysis [33]. The mentioned data visualization techniques provide visual representations of data that can convey information directly and intuitively to the user [34].

Figure 2 Example of pollution on a map, display of measurement results of pollution in the world on the World's Air Pollution portal [32]

Figure 3 Pollution display in Zagreb, map display with the total pollution index [32]

Sometimes several types of pollutants and their concentrations are measured to assess air quality, such as small particles (PM 2.5), large particles (PM 10), ozone, nitrogen dioxide, sulfur dioxide, carbon monoxide, and pollution index (AQI). When representations need to contain multiple variables, displays such as simple numerical representations, line graphs, bar graphs, stacked bar charts, area graphs, maps, heat maps, and scatter diagrams are often used, as seen in Fig. 3 and Fig. 4. In the mentioned representations, a process of visual mapping of information is required, which includes a phase of data pre-processing for cleaning, selection, formatting, and normalization of raw data [34]. This is followed by mapping data objects into visual objects and selecting visual properties that represent data attributes, followed by the user's use of information [34].

Hu et al. [35] designed a *HazeWatch* system based on a portable sensor and communication technologies. The system analyses the data through the visualization of pollution of a certain area on the geographical map and the visualization of personal exposure. A map with the area of pollutant presence is used to visualize the concentration of pollutants, while an area graph was used to show personal exposure, see Fig. 5. By combining the mentioned display modes, optimal visual visibility of the data was obtained.

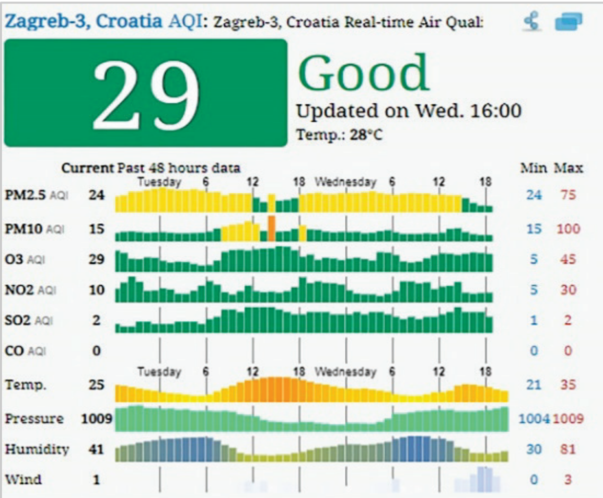


Figure 4 Pollution display in Zagreb, bar graphs of air quality at a particular location [32]

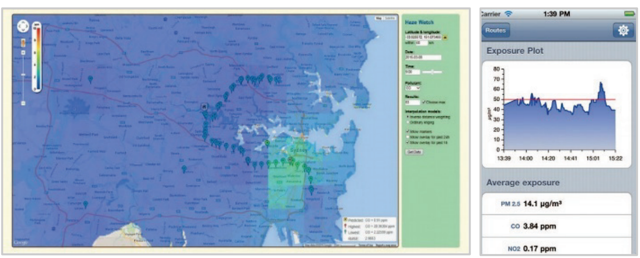


Figure 5 Pollution display in the HazeWatch application, display of pollutant concentration on a map (left), personal exposure display (right) [35]

Table 1 Modified scheme of the hierarchy of perceptual tasks according to the scheme of Alberto Cairo [22]

Allows accurate estimates	Position next to common units	
	Position next to identical, uneven units	
	Length	
	Direction/slope and angle	
	Area	
	Volume	
	Shading and saturation	
Allows general estimates	Hue	

When choosing in which way to present certain information, it is important to consider the hierarchy of elementary perceptual tasks (coding methods) [22]. Cairo [22] presented a modified hierarchy scheme, see Table 1, originally designed by statisticians William S. Cleveland and Robert McGill in the 1980s. Using a hierarchy scheme, one can define which representation is required for a particular type of data depending on the perceptual task the observer is performing. The displayed table indicates the premise that as the position of the visualization mode within the scheme increases, the observer will interpret the information faster and more accurately [22]. Nevertheless, the use of visualization elements located at the bottom of the table does not necessarily result in poor visual representation. Cairo [22] points out that the methods in the lower part of the table are appropriate when the goal is not to define accurate estimations but to detect general samples, which is most often the case with air quality measurement displays.

For the analysis of air quality measurement visualizations used in this paper we used visualization available on web-based Croatian platforms such as the portal of the Ministry of Economy and Sustainable Development [36], Eco Map of Zagreb [37], State Meteorological Institute [38], Air Quality Monitoring in the City of Zagreb [31] and World Air Pollution [32]. Also, in addition to these platforms we also analysed the mentioned *HazeWatch* system [35] that has a mobile application.

What is needed for a visualization to be good is reliable information that is visually coded in such a way that the relevant patterns become noticeable, that research is enabled, and that it is presented attractively with clarity in the first place [22]. All the mentioned information visualization interfaces rely on graphically coded device dimensions such as shape, color, size, texture, orientation, and position, and these schemes can be effective in enabling information analysis [39]. Thus, we can observe that in systems in which air quality measurements are visualized, shapes and colors are used as the main visual coding dimensions, as shown in Fig. 6. Shapes and colors give an easy insight into local areas with polluted air, especially when the location can be determined relatively accurately (streets, squares, etc.).

If the data collected by nanosensors are related to entities and their attributes, then graphs that display attributes (on a graph or a map) are suitable for displaying such data, which is visible on the Eco Map of Zagreb portal.

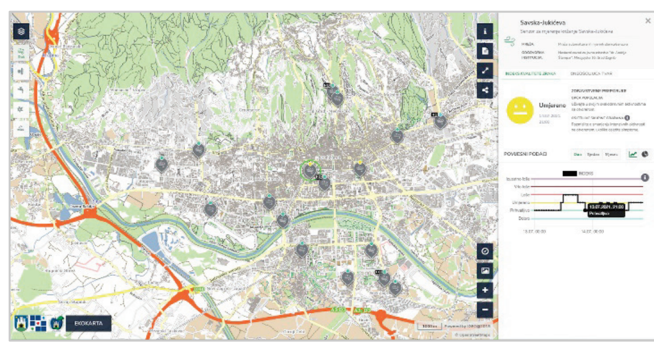


Figure 6 Air quality index display and map on the Eco Map of Zagreb portal [37]

A visual representation such as a map is much easier to use than a textual description when more information needs to be displayed [20]. Displaying data on a map is suitable if spatial data are obtained and it is necessary to define a specific area. An example of such a visualization is visible on the platform of the Ministry of Economy and Sustainable Development, see Fig. 7, in which a map was used as the main presentation medium. The platform can change the way data is displayed through a map, bar graph, line graph, and pie chart. This example provides an insight into the platform in which the user chooses how to display the data and can select the views that he needs at a certain time.

On the map display, a map legend is placed with a description of the gradation of the air quality index through which the information categories are defined (seven terms that are color-coded). It is recommended that no more than eight colors be used to define information categories [39], which was respected in this information visualization. The visual element of color in this example plays an extremely important role and significantly contributes to the ease of perceiving information. Grouping information by color is easy to format, but also clear to the end-user.

Figure 7 Republic of Croatia air quality display on the Ministry of Economy and Sustainable Development portal [36]

On the map of the Ministry of Economy and Sustainable Development portal, geometrical color-coded shapes were used to display air quality index of certain areas.

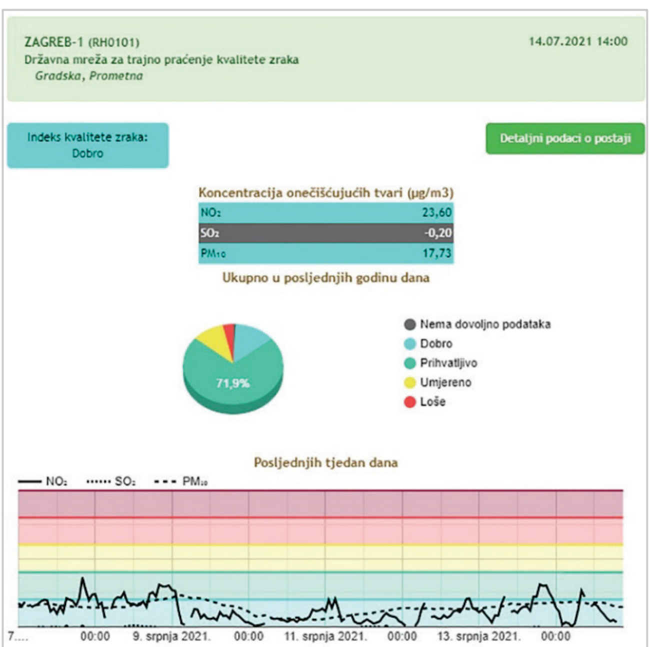


Figure 8 Republic of Croatia air quality display on the Ministry of Economy and Sustainable Development portal [36]

More detailed information can be obtained by clicking the specific shapes, as seen in Fig. 8. This way of presentation is in accordance with the Schneiderman mantra [20]. If the data are time-related, line graphs are suitable for such data display because they display change of data over a period of time. Precisely this way of display was used to display more detailed information about a certain area where the concentrations of pollutants are shown within a multiple line graph, and certain values are highlighted through a numerical display. It can be observed that in the visualization of information in air quality measurement systems, color is a very important element.

To show the relationship between the data sets on the Ministry of Economy and Sustainable Development portal, pollutant indexes can be viewed through a stacked bar chart, as shown in Fig. 9. The graph shows pollutants and their air quality indexes through five color-coded categories. It can be observed that the use of color leads to a very efficient and fast interpretation of information.

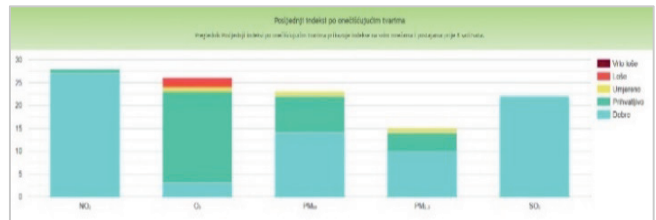


Figure 9 Index display by pollutants on the portal of Ministry of Economy and Sustainable Development portal [36]

If the data obtained from the nanosensors are related to a data network then a line graph or an area graph can be used, as shown in Fig. 10.

Figure 10 Overview of small particles concentration in Zagreb on the State Hydrometeorological Institute portal [38]

Heat maps use color-coding to display categorical data and are also suitable for displaying a data network if one wants to highlight the concentrations of pollutants in the air, see Fig. 11. If multiple types of data need to be displayed, then it is necessary to use complex visualizations (composed of multiple types). Information visualization must possess graphical excellence that refers to a well-designed data display that gives the viewer the most ideas in the shortest time with the least ink in the least amount of space [19]. It is important to emphasize that despite all the guidelines and how well a particular visualization is designed, it cannot withstand the test of being shown to an inattentive, careless, or uninformed viewer [28].

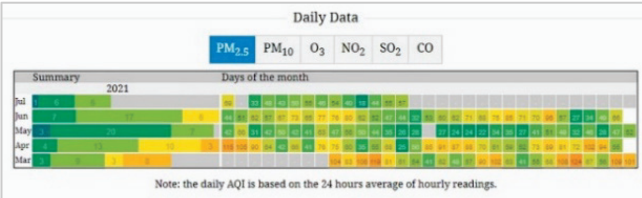


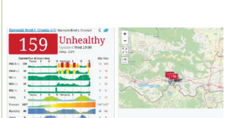
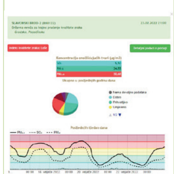
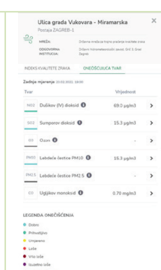
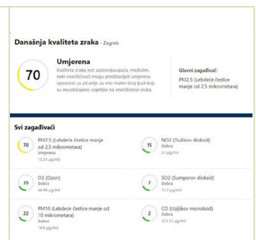
Figure 11 Overview of small particles concentration in Zagreb on the World's Air Pollution portal [32]

4.2 Empirical analysis

In the second (empirical) stage of the research we used a survey that consisted of question regarding the use of air quality information and questions related to five air quality information visualizations. Out of the 59 respondents, 3 (5%) of them stated that they monitor air quality data, 42 (71%) that they sometimes monitor air quality data, while 14 (24%) of them do not monitor air quality data. From the frequency of monitoring air pollution data (AM=1.9) we can conclude that respondents sometimes monitor such data. Also, respondents cite various media through which they monitor air quality data. Most respondents often use web portals (33, 58%), then TV news program (24, 42%), mobile weather forecast applications (16, 28%) and to a lesser extent smart watches (2, 4%) and social networks (1, 2%). From the above results, it can be concluded that the respondents review the data during the review of other general news on web portals or TV. Awareness of the importance of data is evolving, which is confirmed by the following answer, where two groups of respondents are almost equally represented. Those groups are respondents that monitor air pollution data sometimes (23, 40%) and due to warnings about increased concentrations of pollutants (23, 40%), while to a lesser extent they monitor them before external physical activity (4, 7%), daily (2, 4%), or when there is fog outside (2, 4%).

From the data that respondents most often follow, they state that "they do not inspect certain pollutants individually, but cumulatively" (29, 51%), while they equally emphasize the monitoring of carbon dioxide, small particles (PM 2.5), large particles (PM10), and ozone (7, 12%). Some respondents follow data on sulfur dioxide (5, 9%), and some on nitrogen dioxide and volatile organic compounds (2, 4%). The obtained results indicate that the respondents were not sufficiently informed on how a particular pollutant affects health or the environment, but for now general information on air quality is enough. Respondents rate their competencies for reading and understanding visual representations (visual literacy) as relatively good (AM = 2.9). In the questions related to the visualizations, we used the existing visualizations from some of the mentioned analysed portals, VIZA [32], VIZB and VIZC [36], VIZD [37] and VIZE [40]. Respondents were required to express a degree of agreement with four statements. The statements were: (1) Visual display of data is clear. (2) Information is obtained quickly through the visual display. (3) Air quality data are presented in a clear and understandable way. (4) The colors used in the visual display are understandable. Through these questions we wanted to examine our two hypotheses. From the results, see Table 2, we can conclude that VIZE is the most understandable and clear to the respondents, while VIZC is the least understandable to them. Based on this information we can refute our first hypothesis (H1) that stated that there is no difference in the degree of agreement with the display of clarity and understand ability between the five visualizations. Even though the degree of agreement with the statements is relatively similar for VIZA, VIZB and VIZD, VIZC and VIZE have a different degree of agreement. The reason behind this could be the fact that VIZC is the only visualization that used a bar chart which was less clear to the respondents than the other visualizations. On the other hand, the simplest visualization (VIZE) that used simple color-coded numerical representations for air quality data display was the clearest to the respondents. They also stated that information is obtained quickly in VIZE, that the data are presented in a clear and understandable way and that the colors are the most understandable in this visualization in comparison to the others. If we compare the fourth statement results, we can conclude that the colors used in all visualizations are understandable to respondents and

Table 2 Degree of agreement with the statements (1 = strongly disagree, 2 = disagree, 3 = neutral, 4 = agree, 5 = strongly agree), comparison of all visualizations (average scale values, arithmetic mean (AM) and scatter (SD))

										
Statements	VIZA		VIZB		VIZC		VIZD		VIZE	
	AM (1-5)	SD	AM (1-5)	SD	AM (1-5)	SD	AM (1-5)	SD	AM (1-5)	SD
1. Visual display of data is clear.	3.27	1.08	3.47	1.10	2.93	1.36	3.46	1.28	3.90	.96
2. Information is obtained quickly through the visual display.	3.42	1.05	3.53	1.10	2.85	1.31	3.47	1.18	3.83	1.02
3. Air quality data are presented in a clear and understandable way.	3.42	1.09	3.34	1.18	2.80	1.34	3.56	1.22	3.88	.99
4. The colors used in the visual display are understandable.	3.71	1.25	3.58	1.19	3.25	1.29	3.63	1.11	3.80	1.11

therefore we can confirm our second hypothesis (H2). All visualizations show a scattered response, except for VIZE where responds for statements (1) and (3) are not scattered. Finally, respondents to a large extent (51, 86%) believe that it is good to have an overview of the future trend of pollutant concentration available in such visual representations, while a smaller number point out that they do not care (7, 12%) and that it is not good (1, 2%). Based on this result, we believe that such data should be included in the visualizations so that the users can plan their activities.

5 DISCUSSION

Through the presented examples, principles, and analysis of information visualization, ways of visualization of air quality measurement information are explained in the IoNT system. Since the most important aspect in the field of information visualization is the visual perception and understanding of what is seen, we can draw conclusions regarding the interpretation of data related to air quality based on the descriptive and empirical analysis that we conducted. When defining any visualization, it is important to emphasize that while perceiving visualizations, our previous knowledge and expectations play a crucial role [23]. Design of visualizations is not only based on principles, but also on a combination of multiple factors [41]. Prior knowledge and existing mental models are important in any data visualization. Psychologist Stephen Kosslyn presented the principle of appropriate knowledge in which effective communication between a designer and an observer requires a shared understanding of what the graph represents and how the data is coded or symbolized on the graph [23]. The level and degree of understanding certain information visualizations largely depend on the expertise of the visualizations themselves and the viewer. For this reason, we cannot generalize when it comes to understanding data visualizations. Given the type of data related to the measurement of air quality and obtained through nanosensors, it is important to know how to choose the right way to display information.

It can be said that there is no one right way of displaying certain information, but rather that it depends on what should be conveyed to the user. The choice of display depends on how the designer wants to present and communicate certain data. When choosing a display, it is necessary to decide what information needs to be highlighted or displayed and then choose a visualization accordingly. The role of information visualization in systems in which air quality is measured is very important because the user is in direct contact with the visualizations. If the information is not clear to the observer, it will also not be useful to him. It is therefore essential to synthesize the latest research and current practices to provide designers with the knowledge needed to design complex visualizations such as those related to information collected via the IoNT system. Based on the results of the empirical analysis, we can conclude that users perceive simple color-coded numerical representations which display cumulative air pollution data as the most clear and understandable. On the other hand, a stacked bar graph showing different cities and their pollution index in the span of a year was less clear to the participants who expressed a lower degree of understanding the displayed information. From the results we can see that none of the visualizations have the arithmetic mean equal or higher that four. This means that further research is needed to examine which of the visualization elements can be improved to be clearer the end-user.

The air quality measurement system intertwines the fields of nanotechnology, Internet of Nano-Things, and information visualization. These facts lead to the merging of different disciplines and the need for mutual understanding by all participants involved in the process. In the interdisciplinarity of the field lies the challenge of visualizing complex data that are nowadays increasing more and more. In order not to get lost in the sea of meaningless data, it is the responsibility of designers to present them in a true, clear, and useful way to the users who will then be able to draw their conclusions and ask new questions. Since this field is relatively new, the limitation of this research is the lack of literature which combines all the mentioned fields. Also, previous knowledge and expectations of users, as well as the lack of interactivity of visualizations in the survey, were a limiting factor in the empirical analysis.

6 CONCLUSION

Air quality monitoring has become a global imperative. IoNT systems have greatly contributed to the simple and effective solution of such a complex problem. These systems provide a quick and more parametric insight into air quality that can be applied to all locations on the planet. Problems with IoNT air quality monitoring arise in the processing and visualization of data, which an unqualified user should be able to interpret and use in everyday life. Designers have a significant role in solving this problem by using the knowledge of psychologists, mathematical and environmental engineers and trying to present the information to the general public in a user-friendly way. The information visualization of the mentioned data is complex due to the need to present qualitative and quantitative air quality data that are combined with geographical data. Proper selection of visual elements along with a good visualization process, can enable the user a high level of cognitive perception. The choice of visual display depends on the amount and type of information that needs to be visualized. For further research, we propose a more extensive empirical analysis which would include a test with different variables in specific graphs used in air quality information visualizations (e.g. color used in a bar chart). Also, interactive visualizations would bring us more conclusions regarding visual perception since these visualizations mostly exist inside an interactive environment. Furthermore, it would be interesting to research whether visualizations showed on mobile devices are perceived differently than those on a desktop which is what we focused on in this research. Finally, we recommend developing new types of information visualizations by combining the most successful parts of existing visualizations (based on our empirical research results) or designing fully innovative visualizations.

This will contribute to the clarification of which elements are most effective for perception and understanding of air quality data.

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