Medical Dashboards and Medical Data Visualization Systematic Review

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***Abstract*—This paper examines the incorporation of human-computer interaction (HCI) principles into the design of medical dashboards in healthcare settings. In the context of ever-expanding datasets in healthcare, medical dashboards are crucial for supporting critical care decisions by enabling visualization and interaction with extensive data sets. However, the success of these dashboards is heavily influenced by their design and interaction methodologies. This research examines various aspects of HCI in medical dashboards, emphasizing their usability, the efficacy of human-machine interactions, the predictability and enhancement of user behavior through visualization techniques, and the integration of machine learning to enhance dashboard functionality. Through a structured review of the literature, this study aims to shed light on the current state and future directions of HCI applications in medical dashboards, with a particular emphasis on improving clinical decision-making and streamlining clinical workflows.**

***Index Terms*—Human-Computer Interaction, Medical Dashboards, Medical Data Visualization, Human-Machine Interaction, Medical Informatics**

I. Introduction

The main goal of medical informatics is to analyze large and diverse datasets to support critical care decisions. Providing optimal medical care in a hospital requires frequent diagnostic tests, organ function monitoring, and consultations from various healthcare professionals. However, the massive volume of continuously generated data makes it difficult to quickly assess a patient's condition. Physicians and other healthcare professionals often need to gather essential data from multiple sources and compile it into a comprehensive profile of the patient's current state. Furthermore, data collected from these sources are often presented in a manner that complicates the identification of trends and correlations between different variables. Data visualization, as shown in Fig. 1, plays an increasingly crucial role in the examination and interaction of large data sets. Digital data dashboards are widely used in various fields for performance management, but their evaluation in the literature is limited due to their differing scope and implementation. As the healthcare industry continues to evolve, the integration of advanced HCI principles with medical dashboard design is crucial. The following research questions guide our investigation into the integration of HCI with medical dashboards.

1) *In what ways do various interaction techniques influence the usability and satisfaction of medical dashboards in specific healthcare settings, such as intensive care units or routine check-ups?.*
2) *What is the role of human-machine interaction in the effective implementation and use of medical dashboards, and how can these interactions be optimized to improve clinical decision-making?.*
3) *Can user behavior and effectiveness in using medical dashboards be predicted or improved through specific visualization strategies or training programs?.*
4) *How can the integration of machine learning algorithms and HCI principles be used to enhance the functionality and predictive capabilities of medical dashboards? What challenges and opportunities does this integration present for precision medicine and optimized clinical workflows?.*

This study aims to review the current state of Human-Computer Interaction in the context of Medical Dashboards and Medical Data Visualization, with a particular focus on articles that describe systematic reviews of the literature in this area. The study is structured as follows, the methodology used for the study is detailed in Sect. II, while Sect. III introduces the key definitions and frameworks. Additionally, Sect. IV and V present various experimental dashboards and novel input devices relevant to the topic. The future prospects of this field are discussed in Sect. VI, and the conclusion is provided in Sect. VII.

II. Review Method

The systematic literature review involved the search for relevant literature and other stages that can be summarized as follows. First, to obtain a comprehensive understanding of the evaluation of dashboards and other visualization techniques in healthcare, an initial search was conducted in various search engines, including IEEE Scope, ACM Digital Library, Google Scholar, ResearchGate, Springer and ScienceDirect. The search approach included searching for relevant studies in the titles, abstracts, and keywords using a mix of phrases, including those derived by affixation. The terms used are dashboard, human-computer interaction, visualization, human-machine interaction, and medical. The initial search yielded a collection of 30 articles; however, after a thorough examination of the abstracts and introductions, we narrowed the selection down to a total of more than half of the articles. A paper was considered relevant if it focused on dashboards or

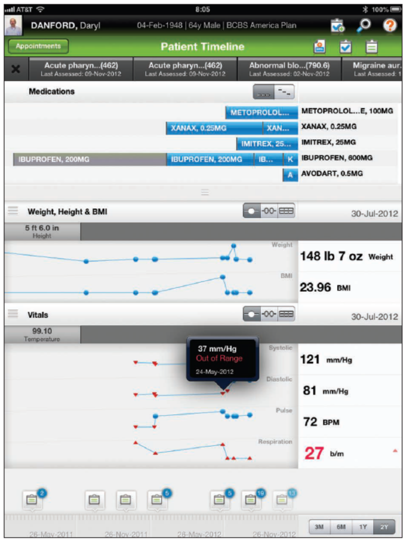


Figure 1. Medical Dashboard. Source [1]

systems that incorporated visual information or manipulation and referred to the healthcare domain. Additionally, it was considered advantageous if the paper provided an evaluation, assessment, or measurement of the quality of the dashboard or system. Subsequently, all the papers were arranged in a table with the following columns: Year, Authors, Title, Venue, Journal/Conference, Number of citations, Key results, Notes, Output, Input, Experiment, Number of Participants, Future Research/Conclusion, Keywords, Link, Search Engine, and Chosen. This organization aimed to facilitate a comprehensive review of each article by simplifying the process of examining the acquired data.

III. Definitions and Frameworks

To understand the upcoming chapters, it is essential to explore specific definitions and introduce two frameworks. Andreas Holzinger, in his article [2], provides key definitions such as Human-Computer Interaction (HCI), which involves understanding and improving the interaction between humans and machines, and Knowledge Discovery, which is closely related to machine intelligence and the development of automated data mining algorithms. It is also important to be familiar with certain acronyms: ECG, which refers to the medical procedure that records heart activity; ICU, which stands for Intensive Care Unit, a hospital facility for patients with severe conditions requiring specialized care; and magnetic resonance imaging, or magnetic resonance imaging, a medical imaging technique that provides detailed visualization of internal body structures.

The discussion can now move to the description of two main frameworks: the first by Zhuang in the article [3] and the second by Lechner in the publication [4]. Zhuang's framework identifies seven evaluation scenarios that cover various categories of evaluations found in their literature review. They provide definitions and identify common assessment questions, measures, and obstacles associated with each scenario. These evaluation scenarios are grouped into three themes: interaction effectiveness, user experience, and system effectiveness, allowing a comprehensive examination of the diverse aspects and dimensions of the evaluated dashboards. In contrast, Lechner's framework offers specific guidelines for building a dashboard. Instead of focusing on specific evaluation criteria, Lechner's framework provides guidance on the overall design and construction of a dashboard. These guidelines serve as recommendations for creating an effective and user-friendly dashboard. According to Lechner's guidelines, activities within the dashboard should be categorized into routine or extraordinary events and emergency/urgent alerts. The design of the dashboard should adopt a minimalist aesthetic approach with the aim of simplicity and clarity. Inline guidance is recommended, using easily understandable labels to help users navigate and understand the dashboard's features. In addition, users should be able to access specific details about a particular location by clicking on a location marker, enhancing their ability to gather relevant information efficiently. The main objective of understanding a framework is to assess the impact of the interaction on task performance and establish a long-term relationship between the user and the dashboard. By understanding the framework, one can evaluate how effectively the interaction with the dashboard enhances task performance and contributes to a positive user-dashboard relationship over time.

IV. Experimental Dashboard

At the beginning of the 21st century, the field of medical informatics concentrated on investigating the doctor office system, a subset of the broader order entry system, or multi-dimensional data as extensively discussed in [5]. In particular, the article [6] introduces a model that efficiently leverages a patient's order history to provide clinical support functions. This model consists of three main components: information extraction, information visualization, and data entry. Specifically, the authors introduce an innovative viewer named the ”SAKURA-viewer” to display order data on the screen. This viewer is designed to identify order patterns and clearly represent the order history. By integrating this viewer into their workflow, operators can gain valuable insights into the patterns and trends of the order data, helping to improve decision-making and analysis. The study [1] emphasizes that evolving health informatics systems have the potential to revolutionize health and healthcare programs worldwide, but achieving this vision requires significant effort from many people. Exploring data sets and uncovering correlations between them to derive meaningful insights is challenging but also offers opportunities to identify patterns, relationships, clusters, gaps, and outliers. As research has advanced, there has been a focus on aspects such as medical data visualization systems in specialized environments such as the ICU, as illustrated in the paper [7] by Anthony Faiola.

Furthermore, there has been a focus on visualizing specific medical examinations such as ECG, as shown by Claudia

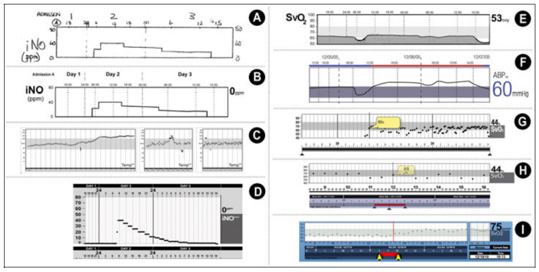


Figure 2. ICU Dashboard. Source [7]

C. Gutiérrez Rodriguez in the paper [8], or more general approaches, as demonstrated in the paper [9] by Margit Pohl. These three authors have employed a similar approach by combining basic and well-known visual representation techniques with substantial interaction techniques tailored to medical needs. They have utilized data from various bedside biometric devices and healthcare provider data sources. Additionally, Claudia C. Gutiérrez Rodriguez, compared to the other two papers, has also implemented a Visualization Management function, Fig. 3. This function allows medical experts to interact with data streams in different ways, enhancing ease of use and flexibility.

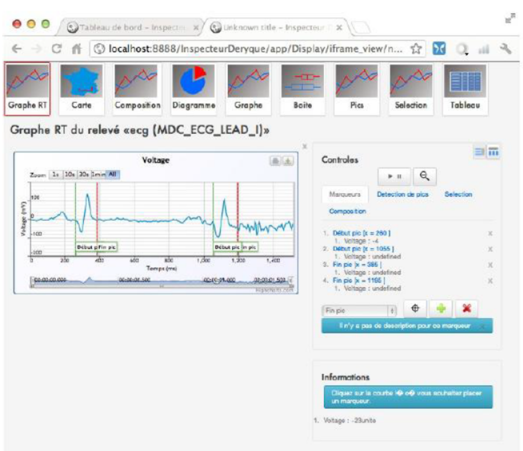


Figure 3. Visualization Management function. Source [8]

Various types of data across the three systems can be illustrated using different methods. Numerical data can be shown with line plots and bar charts, while nominal data can be represented with event charts and timeline charts. Beyond these fundamental representation methods, the systems include five advanced techniques: semantic zoom chart, step chart, silhouette graph, horizon graph, and document browser. These advanced methods adjust to the available screen space and can present different levels of detail according to the user's needs and preferences.

A related study by Ainhoa Yera, referenced in [10], utilizes a web dashboard named SMASH, as shown in Fig. 4, to identify patients at risk of unsafe medication practices in general practices. The study examines whether user interaction data on a medication safety dashboard can reveal visual behavior patterns. The findings suggest a link between mouse activity and visual behavior in terms of cognitive load.

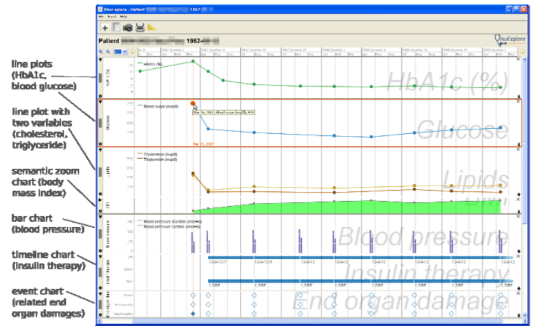


Figure 4. SMASH Dashboard. Source [10]

All the referenced studies carried out a survey where a limited number of doctors, between 3 and 128 participants, evaluated the system using a scale from '5' (highest) to '1' (lowest), achieving outstanding results for the proposed models.

V. New Inputs Device

As noted in [11], the visualization and exploration of three-dimensional medical image data, such as CT, MRI, ultrasound, or PET, represent a crucial application area within scientific visualization. Initial efforts in medical visualization concentrated on effectively presenting medical image datasets using techniques such as direct volume rendering or isosurface rendering with shading. These methods aimed to make efficient use of graphics hardware and improve image quality, for instance, through pre-integrated shading. Some researchers have highlighted the limitations of the traditional keyboard/mouse approach to explore these data and have proposed alternative interaction methods to address these limitations. For example, in [12], Christian Krapichlel suggests an eye-tracking approach, where the user's eye movements are monitored using biosignals, allowing them to control and navigate the visualization based on their gaze. In the paper [13] by Michael Teistler, the authors describe a method that enables users to define the view of the 3D virtual scene simply by moving their heads or walking, providing a more immersive and intuitive interaction experience using a head-mounted display combined with a photographic sketch of the human body. Another approach involves hand gesture recognition with a data glove or special 3D cameras such as the Kinect, as studied by Mohammad Riduwan in [14] and Yusman Azimi Yusoffa in [15], where users can manipulate and interact with the virtual environment using hand movements. Once the depth data has been processed, the next step is the segmentation process, where the hand images are separated from the background images. This is achieved by defining a specific depth range corresponding to the hand gesture images. Subsequently, the system can identify and extract the regions of the image containing the hand gestures. Some of the gestures used in the two documents are illustrated in Fig. 5.

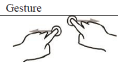
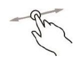
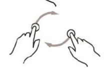
Finger Gesture	Hand Detection	Description	Gesture
Zoom In/Out	Using one-finger from both hand	To gain better focus of a region with large scale factor	
Spread/Pinch	Using two finger from one hand	To gain better focus of a region with small scale factor	
Drag	Using a finger from a hand	To point out the area of volume and drag in or out the volume of the displays region	
Rotate	Using a finger from each hand	To rotate the 3D volume in 3D space	

Figure 5. Finger Gesture Identification. Source [14]

Besides conventional input methods, there are unconventional ways to provide input in certain scenarios. For instance, Olszewska discusses in [16] the use of human brain activity as an input source. This method employs techniques like MVAR (Multivariate Autoregressive) and NN (Neural Networks) to interpret and convert brain signals into meaningful data inputs for interaction and feedback in data visualization.

Specifically, Brain-Computer Interfaces (BCIs) are a unique form of HCI that enable hands-free communication and control systems. They are crucial in assistive technologies and offer a novel way to interact with computers and other devices. BCIs capture and interpret bio-electrical signals produced by the brain during specific mental activities, using them to initiate actions on computers, machines, smartphones, or robots. This creates a mind-based communication system, allowing users to interact with technology solely through their mental processes, eliminating the need for physical input or output pathways. These alternative interaction methods aim to enhance user experience and improve the exploration and analysis of medical imaging data in virtual environments.

VI. The Future

The future of medical dashboards involves the integration of HCI principles with newly developed machine learning and data-driven prognostic algorithms to improve decision-making processes. Using machine learning algorithms and data-driven models, medical dashboards can process large volumes of patient data, recognize patterns, and produce predictive insights. The principles of HCI ensure that these sophisticated algorithms are displayed in a user-friendly and intuitive way, allowing healthcare professionals to interact with the system effectively and make well-informed decisions. Two notable papers on this subject are [17] by Leonardo Rundoa and [18] by Richard Osuala. Rundoa's paper offers an extensive review of the latest advancements in machine learning, particularly focusing on their applicability in clinical decision making. The paper serves as an excellent reference for understanding the latest developments and their practical applications in medicine. Examines how these techniques can improve the decision-making process in clinical settings, ultimately leading to better patient outcomes and more efficient workflows. In contrast, Osuala's paper describes a portable web-based interface that allows healthcare professionals to interact with newly developed machine learning and data-driven prognostic algorithms (Fig. 6). The core aspect of the model, on which the visualization is based, involves vectors with binary entries. This simple representation allowed the creation of a sleek design that quickly highlights important features in a patient's medical history. The prediction model used in the study is based on the diagnostic history vector, focusing on the 30 most common diagnoses.

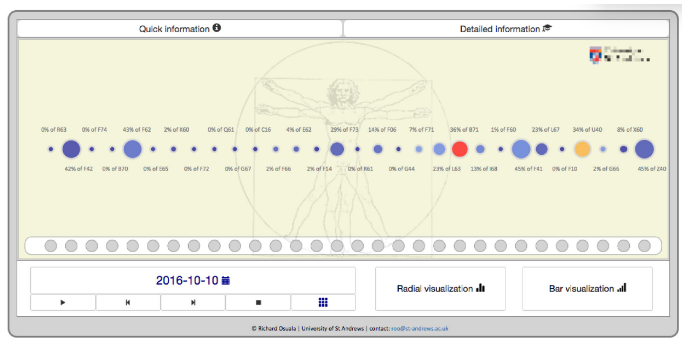


Figure 6. Portable Web-based Interface. Source [18]

It is noteworthy that there are additional areas to explore, such as the innovative approach to intelligent mobile healthcare presented in Mesfer Alrizq's paper [19]. This paper discusses patient monitoring both in hospitals and remotely through wearable sensors. By integrating HCI principles, the architecture aims to develop a user-centric design that improves the usability and effectiveness of mobile healthcare systems. The HCI component emphasizes understanding and addressing user needs, taking into account aspects like user interface design, interaction design, and user feedback. This strategy ensures that the mobile healthcare system is intuitive, efficient, and customized to meet the specific needs of both patients and healthcare providers.

VII. Conclusion

The research examined current literature in the domain of HCI related to Medical Dashboards and Medical Data Visualization. The findings indicated a persistent research endeavor and investigation in this field, concentrating on the effects of medical data visualization on human behavior. The cutting-edge developments in this area are marked by an ongoing quest for knowledge and comprehension aimed at improving the design and efficiency of medical dashboards and data visualization methods.

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